

UNIVERSIDADE DE SÃO PAULO
FACULDADE DE FILOSOFIA, CIÊNCIAS E LETRAS DE RIBEIRÃO PRETO
DEPARTAMENTO DE PSICOLOGIA
PROGRAMA DE PÓS-GRADUAÇÃO EM PSICOBIOLOGIA

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**Memória de trabalho visuoespacial em adultos e em
crianças com dificuldades de aprendizagem**

RIBEIRÃO PRETO

2013

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Memória de trabalho visuoespacial em adultos e em crianças com dificuldades de aprendizagem

Tese apresentada à Faculdade de Filosofia, Ciências e Letras de Ribeirão Preto da Universidade de São Paulo, como parte das exigências para obtenção do título de Doutor em Ciências – Área: Psicobiologia

Orientador: Prof. Dr. Cesar Galera

VERSÃO CORRIGIDA

Ribeirão Preto

2013

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FICHA CATALOGRÁFICA

Garcia, Ricardo Basso

Memória de trabalho visuoespacial em adultos e em crianças com dificuldades de aprendizagem. Ribeirão Preto, 2013.

97 p.: il.; 30 cm.

Tese de Doutorado apresentada à Faculdade de Filosofia, Ciências e Letras de Ribeirão Preto/USP – Área de concentração: Psicobiologia.

Orientador: Galera, Cesar

1. Memória de curto prazo. 2. Memória operacional. 3. Memória visual. 4. Transtornos de aprendizagem.

Ao meu pai (*in memoriam*)

À minha mãe

Aos meus irmãos

AGRADECIMENTOS

Agradeço ao professor Cesar Galera pela oportunidade de realizar meu doutoramento e pela orientação sempre atenciosa e inspiradora. Em seu laboratório encontrei um ambiente produtivo, de muita colaboração, troca de ideias e de experiências – foram anos de intensa aprendizagem.

Agradeço aos professores Cesare Cornoldi e Irene Mammarella por supervisionarem meu estágio de doutoramento na Università degli Studi di Padova.

Agradeço à Universidade de São Paulo, ao Programa de Pós-graduação em Psicobiologia e à Capes pelo suporte e financiamento desta pesquisa.

Agradeço ao professor José Lino Oliveira Bueno por ter acompanhado o meu trabalho ao longo desses anos, sempre contribuindo de maneira positiva.

Agradeço aos funcionários da FFCLRP, por valiosos auxílios técnicos e burocráticos: Igor, Renata, Denise e Maria Inês.

Agradeço aos colegas do Laboratório de Processos Atentivos e Mnemônicos da FFCLRP, pelas frutíferas discussões teórico-metodológicas, pela aprendizagem em conjunto, pelo compartilhamento de ideias e experiências, pelos anos de convivência nessa viagem da pós-graduação: Danila Petian, Hugo Palhares, Jeanny Santana, Juliana Godoy, Karla Farias, Marcelo Araujo, Mariana Pereira, Mikael Cavallet, Paola Carrazzoni e Rafael Vasques.

Estendo os agradecimentos aos amigos da USP, pessoas fantásticas com as quais convivi, compartilhamos muitos bons momentos: Ana Rita Baptistella, Angelita Stabile, Bruno Marinho, Dawit Gonçalves, Diego Padovan, Eduardo Bernardes, Jaqueline Gentil, Kelly Silva, Leonardo Bernardino, Letícia Bizari, Patricia Zuanetti, Richard Spinieli, Roberto Soares, Rui de Moraes e Thiago Brito.

Em Padova também encontrei um ambiente receptivo e de muita colaboração, por isso sou grato aos outros professores e pesquisadores do Memory and Learning Lab: Angelica Moè, Barbara Carretti, Chiara Meneghetti, Erika Borella, Francesca Pazzaglia, Gesualdo Zucco, Patrizio Tressoldi e Rossana De Beni.

Dividi experiências de pós-graduação e de vida com diversos amigos: Alessandra Cantarella, Carla Colomer, David Giorè, Giulia Bucchioni, Micaela Mitolo, Michela Zavagnin e Sara Caviola. Outras pessoas especiais durante a estada em Padova foram Luciano e Lucia do "baretto", parada obrigatória para espressos, tramezzinos e spritz, o seu Silvano e a dona Lorenzina que me "adotaram", fornecendo bicicleta, agasalhos, frutas e guloseimas. Grazie mille a tutti!

Agradecimentos especiais às psicólogas Doriana Tripodi e Arianna Pancera pelo auxílio na coleta de dados dos estudos 2 e 3.

Gostaria também de agradecer às colaboradoras de outras pesquisas realizadas na USP: Carina Tellaroli Spedo, Maria Paula Foss e Marisa Fukuda do HCRP, e Mônica Yassuda da EACH.

Por fim, agradeço à minha mãe e aos meus irmãos, cujo suporte e incentivo foram fundamentais ao longo desses anos.

RESUMO

Garcia, R. B. (2013). *Memória de trabalho visuoespacial em adultos e em crianças com dificuldades de aprendizagem*. Tese de Doutorado, Faculdade de Filosofia, Ciências e Letras de Ribeirão Preto, Universidade de São Paulo, Ribeirão Preto.

A memória de trabalho visuoespacial possui subsistemas especializados na retenção temporária de características visuais e localizações espaciais. Recentemente, diversas pesquisas procuram elucidar os mecanismos de integração (ou *binding*) de características na memória e como objetos integrados são temporariamente armazenados. Nesta tese, abordamos duas questões amplas: Qual a natureza de representações integradas na memória de trabalho? Há um déficit específico na integração de informações em indivíduos com dificuldades de aprendizagem? No Estudo 1, adultos jovens (estudantes universitários) realizaram tarefas de recordar localizações, objetos e conjunções objeto-localização em diferentes condições experimentais de interferência, que poderia ser uma tarefa concorrente visual ou espacial. Uma clara dissociação dupla foi observada: a discriminação de movimento dificultou a recordação de localizações e a discriminação de cores interferiu na recordação dos objetos. Tal interferência seletiva também foi observada na memória para conjunção objeto-localização, indicando que representações integradas dependem da atualização de traços de memória específicos. No Estudo 2, crianças com transtornos específicos de aprendizagem – dislexia e transtorno de aprendizagem não-verbal (TANV) – foram comparadas a crianças com desenvolvimento típico em três tarefas que exigiam a recordação em ordem direta e inversa de sequências de localizações, cores e conjunções cores-localizações. Crianças com TANV apresentaram déficits de memória para localizações e cores, especialmente quando as localizações deveriam ser recordadas em ordem inversa, e não houve diferenças entre grupos na tarefa de cor-localização. Os padrões observados na recordação de cores e localizações em separado não foram observados quando essas informações deveriam ser recordadas de maneira integrada, sugerindo a especificidade de processos de integração de características. Por fim, no Estudo 3, dois grupos de crianças em risco de transtornos de aprendizagem (verbal e não-verbal) foram comparadas a crianças em desenvolvimento típico em tarefas que exigiam memória para cores, formas e conjunções forma-cor. Foi observado que ambos os grupos com dificuldades de aprendizagem apresentaram um déficit de memória para a conjunção forma-cor, com memória preservada para cores e formas separadamente. Isso traz evidências adicionais que problemas de memória para conjunções podem ser generalizados para diversas populações com dificuldades de aprendizagem e desenvolvimento atípico. Resumindo, nosso conjunto de resultados estão de acordo com uma perspectiva associativa da conjunção ou *binding*, isto é, representações integradas resultam de ligações associativas entre diferentes tipos de traços ativados. A memória de trabalho visuoespacial parece funcionar com informações de ambos os níveis – características básicas e objetos integrados.

Palavras-chave: Memória de curto prazo. Memória operacional. Memória visual. Transtornos de aprendizagem.

ABSTRACT

Garcia, R. B. (2013). *Visuospatial working memory in young adults and in children with learning difficulties*. Tese de Doutorado, Faculdade de Filosofia, Ciências e Letras de Ribeirão Preto, Universidade de São Paulo, Ribeirão Preto.

Visuospatial working memory (VSWM) comprises specialised subsystems devoted to storage of visual features and spatial locations. Recently, research has been focused on understanding feature binding in memory and how bound objects are temporarily held in working memory. In the current thesis we have addressed two broad questions: What is the nature of bound visual representations in working memory? Is there a specific deficit in binding in individuals with learning difficulties? In Study 1, young adults were required to recall locations, objects and object-location bindings under visual or spatial concurrent task conditions. A clear double dissociation pattern was observed: movement discrimination mainly disrupted location memory, whereas colour discrimination mainly disrupted object memory. Such selective interference was also observed for object-location memory, suggesting that bound object representations depend on the updating of specific feature information. In Study 2, two groups of children with specific learning disabilities – dyslexia and nonverbal learning disability (NLD) – were compared to typically developing children in three tasks that required forward and backward recall of locations, colours, and colour-location bindings. Only children with NLD have impairments in memory for locations and colours, especially in backward recall of locations, and there were no group differences for the colour-location binding task. The patterns seen in recall of locations and colours separately were no longer present when these features had to be recalled together, suggesting the specificity of binding processes. Finally, in Study 3, two groups of children at-risk of learning disabilities (verbal and nonverbal) were compared to typically developing children in VSWM for colours, shapes, and shape-colour bindings. It was observed that memory for shape-colour binding is impaired in both groups at risk of learning disabilities, whereas memory for either shapes or colours are spared. This provides further support that problems in memory binding may be widespread across different populations with learning difficulties and atypical development. In summary, taken together, our results are in line with an associative view of binding – bound object representation results from associative links between different types of features. VSWM seems to operate on both feature- and object-level information.

Keywords: Short-term memory. Working memory. Visual Memory. Learning disabilities.

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LIST OF ABBREVIATIONS

AD: Alzheimer Disease

ANOVA: Analysis of Variance

CI: Confidence Interval

CRT: Cathode Ray Tube (computer monitor)

LCD: Liquid-Crystal Display (computer monitor)

LD: Learning Disability

M: Mean

MSE: Mean Squared Error

NLD: Nonverbal Learning Disability

PC: Personal Computer

PMA: Primary Mental Abilities

RGB: Red Green Blue (colour notation)

SAS: Supervisory Attentional System

SD: Standard Deviation (of the mean)

SE: Standard Error (of the mean)

STS: Short-Term Store

SVS: Shortened Visuospatial Questionnaire

TD: Typical Development

VLD: Verbal Learning Disability

VSWM: Visuospatial Working Memory

WAIS: Wechsler Adult Intelligence Scale

WISC: Wechsler Intelligence Scale for Children

WM: Working Memory

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CHAPTER 1

WORKING MEMORY AND VISUOSPATIAL COGNITION

1.1 The theoretical framework

Several everyday life activities are based on verbal and visuospatial thinking and depend on temporary storage and processing of information. For example, activities that involve verbal comprehension, reasoning, problem solving, mental calculation, visual imagery, spatial orientation and interaction with the surrounding environment. The concept of working memory refers to the cognitive system that supports online cognition, enabling the temporary maintenance and processing of information during cognitive tasks (Baddeley, 2007; Cornoldi & Vecchi, 2003; Logie, 1995). Several models of the functional structure and mechanisms of working memory have been proposed (for an extensive review, see Miyake & Shah, 1999a), and the comparative analysis by Miyake and Shah (1999b, pp. 448-449) suggests a consensus that working memory is not a unitary system, that is, a domain-general component of cognition, but rather a complex and fragmented system.

The concept of a system comprising a set of specialized components is the cornerstone of the multicomponent model proposed by Baddeley and Hitch (1974), further revised by Baddeley and collaborators (Baddeley, 1986, 2000, 2007, 2012; Baddeley & Logie, 1999; Logie, 1995, 2011a). This model is based on a large body of research in neuropsychology, experimental and developmental psychology. Several empirical evidences support the fractionation of working memory into subsystems, such as specific deficits found in patients with brain injuries (Della Sala & Logie, 1993, 2002), selective interference effects on storage of information (Baddeley, 1986; Logie, 1995), and different developmental rates of working memory components observed in children (Hitch, 1990; Logie & Pearson, 1997; Pickering, Gathercole, Hall, & Lloyd, 2001).

The development of the multicomponent model has been strongly influenced by neuropsychological research. Major contributions derive from the double dissociation technique used to support the assumption of independence between two cognitive functions (Shallice, 1988; see also Teuber, 1955). By comparing groups of patients with specific brain lesions, a double dissociation is observed when impairments in one function do not affect the other and vice versa. For example, a group of patients A has an impaired cognitive function '1' and normal function '2', whereas a group B has normal cognitive function '1' and an impairment in function '2'. In this case, there is strong support that these cognitive functions are independent and have different neural substrates (Shallice, 1988; but for criticisms, see the volume 39, issue 1, of *Cortex* 2003).

The search for functional double dissociations underlies an experimental method widely used in working memory research – the dual-task procedure. When performing a given memory task, a participant should also perform a concurrent task, usually with a low memory load, but with a specific cognitive demand. The rationale is that if both tasks share cognitive resources, then the concurrent task has a disruptive effect on memory. By comparing two memory tasks in two concurrent task conditions, one can identify whether two memory tasks require different cognitive resources. Thus, the goal is to simulate the effects of a brain injury in healthy individuals – a selective disruption of performance in memory tasks (Baddeley, 2012; Baddeley & Hitch, 1974).

Neuropsychological research, which was crucial to establish the functional dissociation between short-term and long-term storage (cf. Scoville & Milner, 1957; Shallice & Warrington, 1970), was also crucial to the fractionation of the cognitive system underpinning short-term retention of information. A major functional dissociation is between verbal and nonverbal subsystems. By analogy with the Digit Span Test of verbal memory based on immediate recall of digit sequences, Milner (1971) and Corsi (1972) introduced a memory span test that requires the recall of sequences of spatial locations – the Corsi blocks test (for a review, see Berch, Krikorian, & Huha, 1998). They showed that patients that underwent surgical removal of the left temporal lobe had a deficit in learning digit sequences and normal learning of block sequences and visuospatial memory. Conversely, patients that underwent surgical removal of the right temporal lobe presented the opposite pattern, that is, normal verbal learning but impaired visuospatial learning and memory. These results suggest that distinct neural substrates are involved in temporary storage and learning of verbal and visuospatial information, a double dissociation also reported in subsequent studies (de Renzi & Nichelli, 1975; see also Basso, Spinnler, Vallar, & Zanobio, 1982; Vallar & Baddeley, 1984).

In the original account of Baddeley and Hitch (1974), the distinction between verbal and visuospatial components was grounded in evidences from dual-task studies. Temporary storage of verbal information was shown to be more susceptible to a verbal concurrent activity in comparison with a visual one, and both visuospatial imagery and memory tasks were shown to be susceptible to visual concurrent activity, but resistant to verbal interference (Baddeley, Grant, Wight, & Thomson, 1975; Brooks, 1967, 1968; Kroll, Parks, Parkinson, Bieber, & Johnson, 1970).

It should be noticed that the previous model by Atkinson and Shiffrin (1968), often considered by some researchers as a unitary system comprising a domain-general short-term

store (Baddeley, 1986, 2000, 2007; Logie, 1995), had already proposed that visual, verbal and probably other types of information could also have their own storage systems. However, the authors opted to simplify the terminology by using the term *short-term store* (STS) instead of *auditory-verbal-linguistic store* (a-v-l store) – "Restricting the term to the STS mode does not imply that there are not other short-term memories with similar properties " (pp. 24-25).

Therefore, there is more continuity than rupture between the Atkinson & Shiffrin (1968) and the Baddeley and Hitch (1974) models. In the multicomponent model, the main structural novelty was the general processor, or central executive, shared by the verbal and visuospatial subsystems. In order to test the hypothesis that working memory plays a crucial role in cognitive activities, as predicted by the Atkinson and Shiffrin (1968) model, participants performed verbal reasoning and comprehension tasks in different memory-load conditions (no load, three or six digits load). The hypothesis was that the increasing load would disrupt performance in reasoning and comprehension. The expected effect on correct responses was not observed, yet the memory load increased response times. Thus, Baddeley and Hitch (1974) proposed that the core of the working memory system is an executive component that shares storage and processing resources, explaining why a higher load reduces processing speed without disrupting accuracy.

One can also consider that the central executive reorganised the previous model of Atkinson and Shiffrin (1968), which did not specify in the architecture of the cognitive system how the *structural aspects* of memory (i.e., the storage systems) interacted with *control processes* that are under the control of the subject (e.g., rehearsal, coding and recovery strategies). In fact, one of the main contributions of this work was to recognise that these processes should be incorporated by a memory model (Shiffrin, 1977). Such ideas were crucial to Baddeley and Hitch (1974) propose a hierarchical model in which the highest level is responsible for controlling the flow and the storage of information in working memory.

Other studies have highlighted the importance of identifying and separating the processes that are under the control of the subject from those processes that are automatic (cf. Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Indeed, in a subsequent revision, Baddeley (1986) adapted as a model for the central executive the *supervisory attentional system* (SAS) of Norman and Shallice (1986). According to the SAS, action has two levels of control – a relatively automatic one, based on schemata derived from habits, and another directly responsible for controlling behaviour. In particular, the central executive is assumed to control attention during memory tasks, setting the focus of attention, inhibiting irrelevant information, dividing attention and task switching (Baddeley, 1996).

In summary, the development of the multicomponent model has been mainly focused on fractionating the structure of the working memory system, identifying storage and processing mechanisms. More recently, there is a trend towards investigating the integration or binding of different kinds of information in working memory. Although the functional independence between verbal and visuospatial storage is well grounded in empirical data, there is also a number of evidences that these subsystems interact with each other, as well as with long-term memory processes (Baddeley, 2000). For example, in some complex tasks, working memory capacity exceeds the amount of information assumed to be held in single storage systems. This is because participants may *chunk* information, that is, integrate similar, meaningful items into smaller, coherent sets. In addition, participants may employ visual imagery strategies to support verbal memory and vice versa, that is, they may use verbal labels to enhance retention of visual information. Thus, Baddeley (2000) introduced the episodic buffer, a component dedicated to bind information into multimodal codes and to temporarily hold them, providing an interface between the verbal and visuospatial subsystems and long-term episodic memory.

In the following sections, we review visuospatial cognition and working memory (Sections 1.2 and 1.3), covering issues regarding further fractionations in visuospatial memory (1.3.1) and the maintenance of bound representations (1.3.2). We then review some practical issues regarding assessment tests and visuospatial deficits in children with learning disabilities (Sections 1.4 and 1.5). Finally, we summarize in Section 1.6 the experimental studies of the current thesis.

1.2 Visuospatial cognition

Visuospatial abilities are involved in a variety of everyday activities that require interaction with objects, spatial orientation and navigation, as well as mental imagery of objects, situations and pathways. These abilities are prone to individual differences, different ageing profiles, developmental disabilities, and can be specifically impaired by brain lesions (Cornoldi & Vecchi, 2003). Hence, assessment of visuospatial skills is important for both theoretical and applied reasons.

In line with different sources of evidences, other multicomponent views of cognition recognise a specific visuospatial high-order component in parallel with a verbal one. For example, in the psychometric domain, intelligence test batteries such as the Primary Mental

Abilities (PMA; Thurstone & Thurstone, 1947) and the Wechsler intelligence scales for adults (WAIS; Wechsler, 2008) and children (WISC; Wechsler, 2004) assess both verbal and nonverbal, visuospatial abilities, which involve perception, reasoning, and abstract processing of visual and spatial information.

In the field of cognitive psychology, according to the dual coding theory, a specialised cognitive subsystem is responsible for the mental representation and processing of nonverbal information such as visual objects and events, and another subsystem is responsible for dealing with linguistic representations (Paivio, 1971, 1986). Although independent at both structural and functional levels, verbal and visuospatial components of cognition are interconnected and activation in one system may spread to the other, for example, concrete words activate related mental images, whereas visual objects activate their verbal labels. Such interplay produces interesting phenomena concerning learning and memory, for example, a better recall for concrete words than abstract ones (Paivio, 1971, 1986).

Considering the assessment of visuospatial skills in the fields of neuropsychology, psychometrics and cognitive psychology, Cornoldi and Vecchi (2003, p. 16) summarised a set of visuospatial abilities. Some abilities are linked to perceptual processes, such as *planned visual scanning* involved in examining a visual configuration rapidly and efficiently with a particular goal, *visual organisation* required to organise or to complete fragmented patterns and figures, and *visual reconstruction* involved in reconstructing a pattern following a given model. Other abilities are linked to mental imagery such as *image generation* and *image manipulation* respectively involved in creating visuospatial mental images and in scanning or transforming mental images. Finally, other abilities are linked to mnemonic processes such as *visuospatial simultaneous short-term memory* required to remember locations and object positions in a visual scene, *spatial sequential short-term memory* required to remember a sequence of different locations, *spatial orientation* involved in perceiving and recalling spatial information in order to orientate oneself in space, and *long-term spatial memory* required to retain spatial information over time.

According to Cornoldi and Vecchi (2003), most of these abilities require the capacity to activate, retain and/or manipulate memory representations and therefore are linked to visuospatial working memory processes. They also highlighted the complexity of functions and processes underlying this component of working memory, which was initially assumed as a unitary construct and turned out to be much more complex.

1.3 Visuospatial working memory

In the multicomponent model of working memory, the visuospatial sketchpad was once considered to be relatively less studied and known, while studies on the phonological loop prevailed (Baddeley, 2012; Vandierendonck & Szmalec, 2011). In recent years, this situation has changed with the growing interest in this topic due to its theoretical and applied relevance. Visuospatial processes are crucial in many everyday activities and are subject to individual differences and specific deficits, either during development or in pathological ageing (Cornoldi & Vecchi, 2003).

Initially, few considerations were made about the structure of the visuospatial sketchpad, and its functional aspects included the temporary storage of information and the creation and maintenance of mental images (Baddeley, 1986). As a system responsible for both memory and imagery processes, a variety of experimental procedures has been used to assess visuospatial working memory (hereafter VSWM). Regarding mental imagery, the most common procedures include the spatial Brooks task (i.e., to place numbers forming a pathway within a 4 x 4 matrix) and mnemonic techniques such as associating words to places (the method of loci) or to images (the pegword mnemonics) (Baddeley et al., 1975; Baddeley & Lieberman, 1980; Brooks, 1967, 1968; Logie, 1986; Quinn & McConnell, 1996; Quinn & Ralston, 1986). On the other hand, visuospatial memory is investigated by procedures that require memorization of spatial locations, visual patterns or object-locations (Huttenlocher, Hedges, & Duncan, 1991; Igel & Harvey, 1991; Logie, Zucco, & Baddeley, 1990; Phillips & Baddeley, 1971; Phillips & Christie, 1977; Posner & Konick, 1966; Postma & de Haan, 1996).

Recently, there is a trend towards procedures that require temporary retention of information, since imagery tasks also involve verbal and executive resources, that is, other working memory components (Roulin & Monnier, 1994). Furthermore, imagery and temporary visual memory are prone to different patterns of interference, suggesting that imagery and mnemonic processes may be partially distinguished (Logie & Van der Meulen, 2009; Pearson, 2001). Finally, VSWM seems to operate upon distinct visual and spatial representations, stressing the importance of appropriate procedures to assess specific VSWM functions. Next, we review theoretical and methodological implications concerning the nature of mental representations and the structure of VSWM.

1.3.1 Dissociations in visuospatial working memory

An initial account of VSWM by Baddeley and Lieberman (1980) suggested that it mainly operates on representations of spatial nature. A series of experiments showed that performance in the spatial Brooks task was impaired by a spatial-movement concurrent task (to track, blindfolded, the movement of a pendulum), but it remained unaffected by a visual-based concurrent task (brightness judgment). Furthermore, the tracking task disrupted the mnemonic technique of associating words to places, but it also had a minor effect on the association of words to images, leading the authors to argue for a spatial-based nature of VSWM. This issue was further investigated by Logie (1986), who showed that the association of words to images was disrupted by a visual concurrent task, the observation of irrelevant figures, but not by irrelevant speech. Conversely, a verbal mnemonic strategy (rote rehearsal) was disrupted by irrelevant speech, but not by irrelevant images. Taken together, these results show that the visual or spatial nature of the imagery task can explain the selective interference effects observed, and suggest the presence of both visual and spatial representations in VSWM (see also Logie, 2011a).

A similar double dissociation pattern is also observed in memory tasks. This issue was first tackled by Logie and Marchetti (1991), who compared retention of sequences of colour shades and spatial locations under different concurrent conditions. The results revealed that observation of irrelevant figures disrupted memory for colours, whereas a spatial-tapping task disrupted memory for locations. Further behavioural research using dual-task procedures largely document that visual concurrent tasks disrupt retention of visual features (such as colours and shapes) but not of spatial locations, whereas spatial-movement tasks disrupt retention of locations but not of visual features (Darling, Della Sala, & Logie, 2007, 2009; Klauer & Zhao, 2004; Logie & Marchetti, 1991; Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999; Tresch, Sinnamon, & Seamon, 1993).

Neuropsychological reports (Farah, Hammond, Levine, & Calvanio, 1988; Luzzatti, Vecchi, Agazzi, Cesa-Bianchi, & Vergani, 1998; Vicari, Bellucci, & Carlesimo, 2006) and neuroimaging studies (Jonides et al., 1993; Smith & Jonides, 1997; Smith et al., 1995; Wager & Smith, 2003) also provided evidences that different neural substrates are involved in memory for objects and locations. This dissociation seems to be related to the anatomical specialization of perceptual processes in the “what” system responsible for information regarding visual features and object recognition, and a “where” system dedicated to spatial and movement aspects, that is, different types of feature dimensions are processed by feature-

specific structures (Livingstone & Hubel, 1988; A. D. Milner & Goodale, 1995; Mishkin & Ungerleider, 1982; Ungerleider & Haxby, 1994).

Under a theoretical point of view, however, the relationship between VSWM and visual processing pathways remains unclear, mostly because researchers tend to assume that mnemonic processes work on mental representations rather than on perceptual information (Della Sala & Logie, 2002). According to some authors, information in working memory are activated long-term memory representations (e.g., Cowan, 2005; Oberauer, 2009) as in the VSWM model of Logie (1995, 2011b; see also Logie & van der Meulen 2009), in which visual inputs activate long-term information that are transferred to a *visual cache*. On the other hand, some authors assume that visual inputs are temporarily held in a *visual buffer*, which is at an earlier stage of processing and still open to direct access of incoming sensorial information, as evidenced by visual noise interferences (Quinn, 2012). In fact, recent evidences from cognitive neuroscience studies indicate that primary areas in visual cortex are also involved in retention of feature information in working memory, together with high-order cortical areas (Harrison & Tong, 2009; Silvanto & Cattaneo, 2010).

Under a methodological point of view, the visual/spatial dissociation has important implications, and a fundamental issue concerns the classification of visual and spatial characteristics of stimuli. Some authors intended by the term *visual* the appearance of stimuli or scenes, composed by features such as colour, shape, size and textures, as well as the relative locations between the objects in a static array, reserving the term *spatial* to more dynamic aspects such as pathways and sequences of movements between locations (Logie, 1995; Della Sala & Logie, 2002). However, the idea that memory for static spatial configurations is supported by visual processes has been subjected to criticisms. Some authors have highlighted that spatial mental representations are more complex, and can be classified as *egocentric* (locations encoded relative to the observer) or *allocentric/configural* (locations encoded as relations between perceptual entities), each supported by different neural substrates (Zimmer & Liesefeld, 2011).

In addition to a visual subsystem, some authors have proposed a further distinction between *spatial-simultaneous* and *spatial-sequential* processes (Cornoldi & Vecchi, 2003; Frick, 1985; Lecerf & de Ribaupierre, 2005; Pazzaglia & Cornoldi, 1999; Pickering et al., 2001; Pickering, 2001), depending on whether the spatial locations are presented simultaneously (Della Sala et al., 1999) or sequentially as in the Corsi test.

In fact, the distinction between three types of VSWM processes is supported by neuropsychological and experimental evidences. A specific impairment in a visual span test

was reported for a group of children with spina bifida, despite the fact that they performed similarly to controls in a series of other visuospatial memory tests (N. Mammarella, Cornoldi, & Donadello, 2003). Regarding spatial processes, case reports showed that children with nonverbal learning disabilities may present a specific deficit for either static spatial configurations or spatial sequences, revealing a double dissociation pattern (I. C. Mammarella et al., 2006). Finally, structural equation modelling showed that a tripartite model of VSWM, in comparison with other traditional models (e.g., Baddeley, 1986; Logie, 1995), provided the best fit of the data regarding the performance of 162 children in several visuospatial tasks (I. C. Mammarella, Pazzaglia, & Cornoldi, 2008).

In summary, assessment of VSWM should carefully control stimuli characteristics, match stimuli presentation conditions (simultaneous vs. sequential), and choose appropriate concurrent tasks (visual-based or spatial-based).

1.3.2 Information binding in visuospatial working memory

Notwithstanding the visual/spatial dissociation and the importance of examining temporary memory for single, separate features, everyday life situations continuously demand the processing and retention of integrated information involving different working memory components. Information binding is a crucial aspect of cognitive functioning and binding processes in working memory have been under systematic investigation only recently (Baddeley, Allen, & Hitch, 2011). Research on VSWM has nonetheless generally concentrated on either spatial or visual processes, but the processes involved in remembering bound visuospatial information are currently under investigation. For example, it is currently being debated whether a specific component such as the episodic buffer is involved – as in cross-modal binding (Baddeley, 2000) – in association with specific neural processes (Mitchell, Johnson, Raye, & D’Esposito, 2000) or whether binding is a result emerging from the spatial and visual components joining forces (Baddeley et al., 2011; Logie, 2011a).

According to Elsley and Parmentier (2009), if the episodic buffer is involved in binding, than we assume a *representational* view of binding, that is, bound objects are held as composite, unitised representations held independently from constituent features (pp. 1702-3). On the other hand, if binding depends on the updating of feature information, than we assume an *associative* view of binding, that is, binding relies on associative links between features. Elsley and Parmentier (2009) derived two hypotheses from this:

if Features A and B yield the creation of a new composite representation C, then interfering with the maintenance of A or B would be of no consequence for the maintenance of C. If, however, binding simply reflects an associative link between A and B, then any damage to one of the features would affect binding. (p. 1703).

Considering that the episodic buffer is assumed to depend on central executive resources, this leads to the hypothesis that memory binding would require more attention than memory for single features (Baddeley et al., 2011; Baddeley, 2000). However, there are converging evidences that attentional-demanding concurrent tasks disrupt to the same extent the retention of individual features and bound objects (Allen, Baddeley, & Hitch, 2006; Allen, Hitch, Mate, & Baddeley, 2012; J. S. Johnson, Hollingworth, & Luck, 2008; Morey & Bieler, 2013), even when objects' features are separated spatially or temporally rendering binding more difficult (Karlsen, Allen, Baddeley, & Hitch, 2010). These results suggest that attention is generally involved in VSWM and support the view that the episodic buffer may be a passive store not directly responsible for binding processes (Baddeley et al., 2011; Karlsen et al., 2010; Morey & Bieler, 2013).

Thus, the current view is that binding occurs automatically within VSWM, which seems to work on integrated object representations consisting of visual and spatial features bound together (Allen et al., 2012; Baddeley et al., 2011; Luck & Vogel, 1997). Given that irrelevant changes in stimuli locations disrupt object recognition memory, it seems that stimuli locations are encoded into working memory even when the spatial dimension is not relevant to the task (Corder, Vasques, Garcia, & Galera, 2012; Hollingworth & Rasmussen, 2010; Jiang, Olson, & Chun, 2000; Olson & Marshuetz, 2005; Santana & Galera, n.d.; Treisman & Zhang, 2006). Other studies have shown that feature information is also relevant to VSWM functioning, specially because features from the same dimension compete for storage capacity (e.g., Delvenne & Bruyer, 2004; Wheeler & Treisman, 2002), bringing support that VSWM operates on both feature- and object-level information (see also Allen et al, 2012; Baddeley et al, 2011).

1.4 Neuropsychological assessment of visuospatial working memory

There is a large number of tasks devised to assess VSWM (for reviews, see Cornoldi & Vecchi, 2003; Mammarella, Pazzaglia, & Cornoldi, 2006; Oberauer, Süß, Schulze, Wilhelm, & Wittmann, 2000; Richardson, 2006), some of which have been useful for the assessment of populations with specific visuospatial deficits. In this section, we present the Corsi test, which mainly evaluates the spatial component of working memory, and a visual short-term memory test originally proposed to assess older populations, which has been useful to identify a deficit in visual binding.

The Corsi blocks task has become popular in the neuropsychological assessment of children and adults. The test apparatus consists of nine blocks randomly placed on a rectangular board (Figure 1.1); the examiner taps a sequence of blocks and the participant is asked to reproduce the sequence from memory. The test begins with short sequences and the level of difficulty increases, adding one block to the sequence until the participant is no longer able to reproduce it correctly. The Corsi test has been used in forward and backward recall directions (Isaacs & Vargha-Khadem, 1989; Kessels, van den Berg, Ruis, & Brands, 2008; Vandierendonck & Szmalec, 2004; Wilde & Strauss, 2002), and its backward version has been useful to discriminate individuals with poor visuospatial skills and working memory, as reviewed in Section 1.5 below.

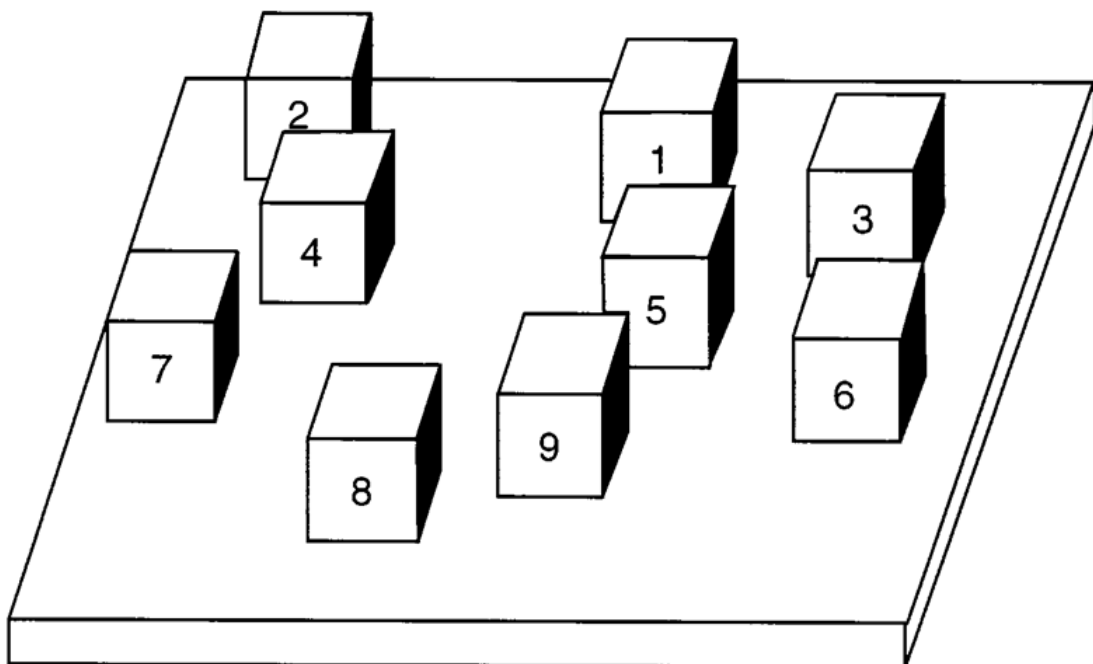


Figure 1.1. Illustration of the original Corsi test apparatus: a wooden board (23 x 28 cm) with 9 blocks (3 x 3 x 3 cm).

Neuropsychological assessment of memory binding is a very recent topic. Evidences indicate that children and older adults have a poorer memory for bound objects than young adults (Brockmole, Parra, Della Sala, & Logie, 2008; Cowan, Naveh-Benjamin, Kilb, & Saults, 2006), indicating that specific age groups are likely to present higher variability in binding tasks and that some individuals may have a deficit in performance. In fact, concerning older adults, there are consistent evidences that a deficit in memory for bound visual objects is characteristic of patients with Alzheimer Disease, a deficit found in comparison with controls and with other patients presenting depression or other dementias (Della Sala, Parra, Fabi, Luzzi, & Abrahams, 2012; Parra, Abrahams, Logie, & Della Sala, 2010). On the other hand, concerning children, developmental research has provided only limited evidence that some clinical groups may have problems in memory binding. Jarrold, Phillips and Baddeley (2007) showed that individuals with Williams syndrome (children and adults) and children with moderate learning disability have an impaired binding of visual and location information in comparison with typically developing children. According to the authors, this deficit may result from poor executive resources and cognitive functioning in children with delayed development. However, given the evidences that binding does not specifically depend on attention, it remains an open question whether the observed deficit may result from an impairment in VSWM.

The visual short-term memory test proposed by Parra and collaborators is computerised and comprises a pool of 72 coloured shapes, the combination between eight shapes (six-sided polygons) and nine colours (cf. Figure 4.2 on page 67). This test assess memory for shapes and colours separately, and for shape-colour bindings. An array with two or three stimuli is presented for memorisation, and after a black interval a test array is presented and the participant should respond whether the arrays are the same or different. On half of the trials, the test array is different: For the shape and colour conditions, two stimuli from the memorised array are replaced by two new stimuli (new shapes or new colours, respectively), and in the binding condition, two memorised stimuli are presented with swapped colours in the test array. This test is quite simple and it has been useful to assess memory for simpler items (shapes or colours) as well as memory for bound items (shape-colour).

1.5 Visuospatial working memory impairments in children with specific learning disabilities

The term *learning disability* (LD) has been used to describe children of average or above average intelligence whose school performance is poor. The most common approach to identify children with LD is to detect discrepancies between intelligence and achievement tests (Fletcher, Lyon, Fuchs, & Barnes, 2007; Swanson & Hoskyn, 2002), indicating difficulties in learning in despite of preserved intelligence skills. Primary manifestations of a LD include deficits in basic academic skills such as word recognition, reading fluency, reading comprehension, writing and arithmetical operations (Fletcher et al., 2007; Reid, 2011).

One major subgroup of LD includes children with dyslexia, who have impaired language abilities such as poor reading, writing and spelling skills. These children have difficulties in understanding written work and displaying knowledge through writing, that is, abilities related to decoding print and understanding grapheme-phoneme relations (Reid, 2011). Common assessment tools of such abilities include pseudoword reading, in which children have to rely on grapheme-to-phoneme transformation rules, and single-word reading, in which decoding should occur without contextual cues.

Another subgroup of children has a neuropsychological profile characterised by impairments in nonverbal abilities, a disorder commonly known as *nonverbal learning disability* (NLD) (Rourke, 1995), but it also has been called developmental right-hemisphere syndrome (Nichelli & Venneri, 1995) or visuospatial learning disability (Mammarella & Cornoldi, 2005a, 2005b). One of the most often considered features identifying NLD is a significantly lower score in tasks measuring visuospatial intelligence than in those measuring verbal intelligence, a consequence of the expected discrepancy between these children's verbal, language-based cognitive abilities and their nonverbal, visuospatial cognitive skills (Cornoldi, Venneri, Marconato, Molin, & Montinari, 2003; D. J. Johnson, 1987; I. C. Mammarella et al., 2009; Rourke, 1995; Weintraub & Mesulam, 1983).

According to Rourke (1995), the NLD syndrome is characterised by deficits grouped into three main areas: neuropsychological, academic, and socioemotional/adaptational. Neuropsychological deficits include difficulties with tactile and visual perception, psychomotor coordination, visuospatial reasoning and memory, as well as verbal aspects such as verbosity and lack of prosody. Academic deficits involve difficulties with graphomotor aspects of writing, reading comprehension, arithmetic calculation, mathematics and science

issues related to problem solving and complex concept formation. Finally, socioemotional and adaptational deficits include problems regarding social perception, social judgement, and social interaction skills, with tendencies to inappropriate behaviours and isolation.

A crucial factor underlying the difficulties encountered by children with NLD seems to relate to VSWM deficits, which would explain the difficulties these children have in a wide range of school and everyday life activities involving the handling of visuospatial information such as mathematics, drawing, and spatial orientation. (Cornoldi, Rigoni, Tressoldi, & Vio, 1999; Cornoldi, Vecchia, & Tressoldi, 1995; Cornoldi & Vecchi, 2003; I. C. Mammarella & Cornoldi, 2005a). For example, Cornoldi et al. (2003) found that a group of children with NLD were particularly poor in the Corsi blocks task, especially when information had to be recalled in reverse order. When Mammarella and Cornoldi (2005b) compared the forward and backward versions of the Digit Span Test and the Corsi task between NLD cases and controls, they found that both groups performed poorly in the backward version of the Digit Span; but in the Corsi task a discrepancy was only seen in children with NLD. These findings support the hypothesis that the backward Corsi involves spatial-simultaneous processes (see Cornoldi & Mammarella, 2008; I. C. Mammarella & Cornoldi, 2005b). By using spatial-simultaneous processes, the sequence of blocks is codified and retained as an overall pattern of locations, that is, a simultaneous mental representation of the pathway as a whole, which recall is facilitated by starting from the last item. Children with NLD, given their low visuospatial abilities and poor VSWM, may have problems in constructing and retaining such mental representation of a pathway.

Regarding children with dyslexia, deficits involving the storage capacity of the phonological loop have been extensively described in the literature (Ackerman & Dykman, 1993; Gould & Glencross, 1990; Helland & Asbjørnsen, 2004; Palmer, 2000), and there are conflicting reports on these children's performance in VSWM tasks. Some recent studies (Jeffries & Everatt, 2004; Kibby, Marks, Morgan, & Long, 2004) found no significant difference between children with dyslexia and controls in a number of spatial WM tasks, while others provided some evidence in support of an impairment in this domain in adults with dyslexia (e.g., Smith-Spark, Fisk, Fawcett, & Nicolson, 2003). The VSWM weaknesses in dyslexics may also differ to some degree from those seen in children with other types of LD. Jeffries and Everatt (2004) draw a comparison between children with dyslexia, children with other LD, and controls, finding that children with dyslexia were comparable to controls in VSWM measures, whereas the other LD group performed worse. Regarding verbal working memory measures, both clinical groups performed worse than controls.

1.6 Thesis overview

The present chapter brought an overview of the multicomponent model of working memory, with particular attention to structural and functional aspects of visuospatial cognition and working memory. Since the introduction of the episodic buffer by Baddeley (2000), research has been devoted to understand how bound information are held in working memory. In the current thesis, we have addressed two broad questions regarding binding: (1) What is the nature of bound visual representations in working memory? and (2) Is there a specific deficit in binding in individuals with impaired VSWM?

In Study 1, young adults were required to recall locations, objects and object-location bindings under visual or spatial interference conditions. We aimed at investigating whether a bound object held in memory is prone to selective interference. A negative result (i.e., either no interference or a general interference) would support the view that a complex, unitised representation is held, supposedly in the episodic buffer. On the other hand, selective interferences would support that a bound object depends on information held in feature stores.

In study 2, children with specific learning disabilities were compared to typically developing children in three tasks that required forward and backward recall of locations, colours, and colour-location bindings. One aim was to investigate whether an impairment in backward recall by children with NLD is widespread for other VSWM processes, and another aim was to investigate whether children with learning disabilities have a deficit in colour-location binding.

In study 3, children at-risk of learning disabilities were compared to typically developing children in visual short-term memory for colours, shapes, and shape-colour bindings. Our aim was to ascertain whether children with poor learning skills in general have a deficit in binding, or whether this deficit would be specific to children with poor visuospatial skills.

CHAPTER 2

STUDY 1

SELECTIVE INTERFERENCE EFFECTS ON WORKING MEMORY FOR LOCATIONS, OBJECTS AND OBJECT- LOCATION BINDINGS

2.1 Introduction

The dissociation between visual and spatial components in working memory is well grounded in empirical data, as discussed in session 1.3.1. However, it has been usually observed by using discrepant tasks that require memorisation of either spatial locations or visual characteristics, and interference effects might be due to confounding factors derived from discrepancies in tasks and cognitive demands. According to Klauer and Zhao (2004), a common working memory resource may be overloaded when memory and concurrent tasks are both visual or both spatial: Such trade-offs between tasks would be reflected in different levels of performance in concurrent tasks. In order to rule out this interpretation, performance in concurrent tasks should be stable across different memory tasks.

Klauer and Zhao (2004) also raised a number of alternative explanations to the visual/spatial dissociation such as *differential processing* involved in memorisation of visual displays or sequences of locations, the *locus of dissociation* that may be related to processing stages other than temporary storage (e.g., sensorial memory, encoding or retrieval stages), a *similarity-based interference* resulting from overlapping features between stimuli held in memory and those presented during a concurrent task, or the *involvement of verbal and executive components* given that memory tasks are not a pure measure of a single working memory component.

In order to address these issues and based on a previous study of Tresch et al. (1993), Klauer and Zhao (2004) proposed two simple memory tasks matched for cognitive demands, that is, similar encoding, maintenance and retrieval conditions. Both tasks were based on a brief presentation of one stimulus and, after a retention interval of 10 seconds, eight stimuli were presented and the participant had to indicate which one had been presented. For the spatial memory task, a dot appeared at one out of eight possible locations, and for the visual memory task a Chinese ideograph (out of eight) was presented in the centre of the screen. Thus, both memory tasks followed the same "pick one of eight" format. Concurrent tasks performed during the 10 seconds retention interval were also matched for cognitive demands by equating overall difficulty. The movement discrimination task required participants to find one static asterisk among 11 moving asterisks, and the colour discrimination task required participants to classify a colour as being red or blue.

In a series of experiments, Klauer and Zhao (2004) observed consistent double dissociation patterns regardless of experimental manipulation controlling factors such as time

for memory consolidation, long-term memory influence, verbal strategy, stimuli similarities and executive processes. Taken together, the results provided strong evidences for a visual/spatial dissociation in working memory.

Despite the fact that Klauer and Zhao (2004) matched the cognitive demands for memory tasks, the tasks were based on memorisation of either visual or spatial information. The assessment of memory for single, separate features has been important to better understand the structure of VSWM, however, it is artificial if we consider that environmental information is complex and visual features are bound to spatial information during visual perception (Treisman, 1996). Given that recent research on VSWM tend to consider such complexity, in the present study we have addressed the question whether selective interference effects may be also observed for bound object representations temporarily held in memory. What kind of interference may occur in a task that presents visual objects in different locations and, after a retention interval, participants are required to place each objects in its respective location?

A previous study by Zimmer, Speiser and Seidler (2003) aimed at investigating visual or spatial interferences on an object-relocation task and brought no promising results. They presented for 8 seconds visual arrays containing four stimuli, and after a retention interval of 10 seconds the participants had to place the objects in their places. They found no interference effects on this task, and argued that spatial configurations of objects are codified together with their visual features during perception, and such bound information may have been stored by structures related to episodic memory. Thus, according to the multicomponent model of working memory, object-relocation requires resources from the episodic buffer, explaining why concurrent tasks known to disrupt the visuospatial sketchpad had no effects.

In our view, the task devised by Zimmer et al. (2003) has methodological limitations that may partially explain their results. The visual memory contribution is minimal since the same objects presented for memorisation reappears in the task display without distracting stimuli, rendering the task more spatial in the sense that it requires spatial manipulation of objects. In addition, there was no time pressure and participants were free to change object locations until confirm their responses. Finally, stimuli presentation time of 8 seconds may be too long for a working memory task, which is based on briefer expositions. Taken together, these methodological aspects might have reduced the contribution of the visuospatial sketchpad and enhanced the involvement of the episodic buffer.

2.2 Objectives and hypotheses

We have adapted the procedure devised by Klauer and Zhao (2004) in order to require the concomitant memorisation of visual and spatial information. The "pick one out eight" format was used with Chinese ideographs and locations as in the original study. Instead of presenting an ideograph on the centre, it was presented at one out eight possible locations. After a retention interval of 10 seconds, the eight ideographs and the eight locations appeared on the screen.

There were three blocks of trials according to the task: participants were required to pick one ideograph (memory for object), to pick one location (memory for location), or to pick one ideograph and one location (object-location memory). As in the original study, retention interval had a control condition (black screen), a movement discrimination task or a colour discrimination task.

In summary, this manipulation allowed to investigate how concurrent tasks affected an object-location task, which was simplified to one stimulus (instead of four, cf. Zimmer et al., 2003) that had to be discriminated among distracting stimuli in the memory task, imposing therefore both visual and spatial memory demands. Moreover, memory for objects and for locations were also assessed separately, as in the Klauer and Zhao (2004) study.

According to the hypothesis that VSWM has dissociated visual and spatial components, and following empirical evidences, we predicted that memory for locations would be disrupted by movement discrimination, whereas memory for objects would be mainly disrupted by colour discrimination. Regarding memory for object-location bindings, we considered two alternative hypotheses (cf. Elsley & Parmentier, 2009). If bound objects are held by the episodic buffer, then we expected that memory binding would either remain unaffected (as in Zimmer et al., 2003) or equally disrupted by concurrent tasks (possibly due to attention demands). On the other hand, if bound objects are held in VSWM and are dependent upon temporary visual and spatial information, then we expected that concurrent tasks would selectively disrupt the selection of objects and their locations.

2.3 Method

Participants

Eighteen students (9 females and 9 males) aged between 19 and 34 years ($M = 24.3$, $SD = 3.5$) volunteered to participate in this experiment. The students were recruited at the campus of the University of São Paulo at Ribeirão Preto. Prior to the testing they read and signed an informed consent form. The present study was approved by the *Comitê de Ética em Pesquisa*, FFCLRP-USP (process number 467/2009 – 2009.1.1956.59.0; see Appendix A). All participants reported normal or corrected to normal visual acuity, and none was identified as colour blind as assessed with the simplified 6-plates evaluation of the Ishihara Test (Ishihara, 2008).

Materials and stimuli

A desktop PC was used and a chinrest with head support was placed at approximately 57 cm in front of a 18" CRT monitor. All the experimental procedures were programmed with the E-Prime software (W Schneider, Eschman, & Zuccolotto, 2002).

The stimuli used in the memory task were eight Chinese ideographs measuring approximately 0.7° of visual angle (Figure 2.1a, cf. Klauer & Zhao, 2004) placed inside white squares measuring 0.8° of visual angle (see also Appendix B). A black background screen was used for stimuli presentation and there were eight fixed locations equally spaced along the outline of an invisible circle. The first location in quadrant I was set at 22.5° and the other locations were defined at every 45° along the circle (Figure 2.1b).

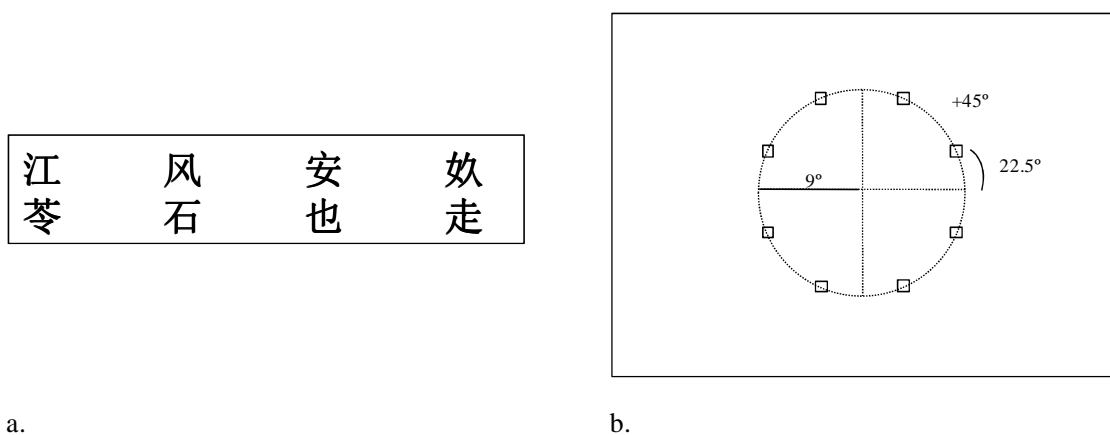


Figure 2.1. Chinese ideographs (a) and locations for stimuli presentation (b) used in Study 1.

Participants had to press the spacebar to start a trial and had to perform articulatory suppression (i.e., to count aloud continuously from 1 to 10) throughout stimulus presentation and retention interval, in order to inhibit the use of a verbal rehearsal strategy. A trial begun with the presentation of a white fixation cross for 500 ms, followed by the presentation of a Chinese ideograph for 500 ms and a visual mask for 500 ms. After a retention interval of 10 seconds, the task display was shown with the eight locations and the eight Chinese ideographs in two rows of four centred on the screen (Figure 2.2; see also Appendix B for further details). There were three blocks of tasks: Memory for object required a mouse click on the previously presented ideograph and memory for location required a mouse click on the location where an ideograph had appeared; memory for both object and its location (i.e., the object-location binding task) required participants to first click on the ideograph and then on its location.

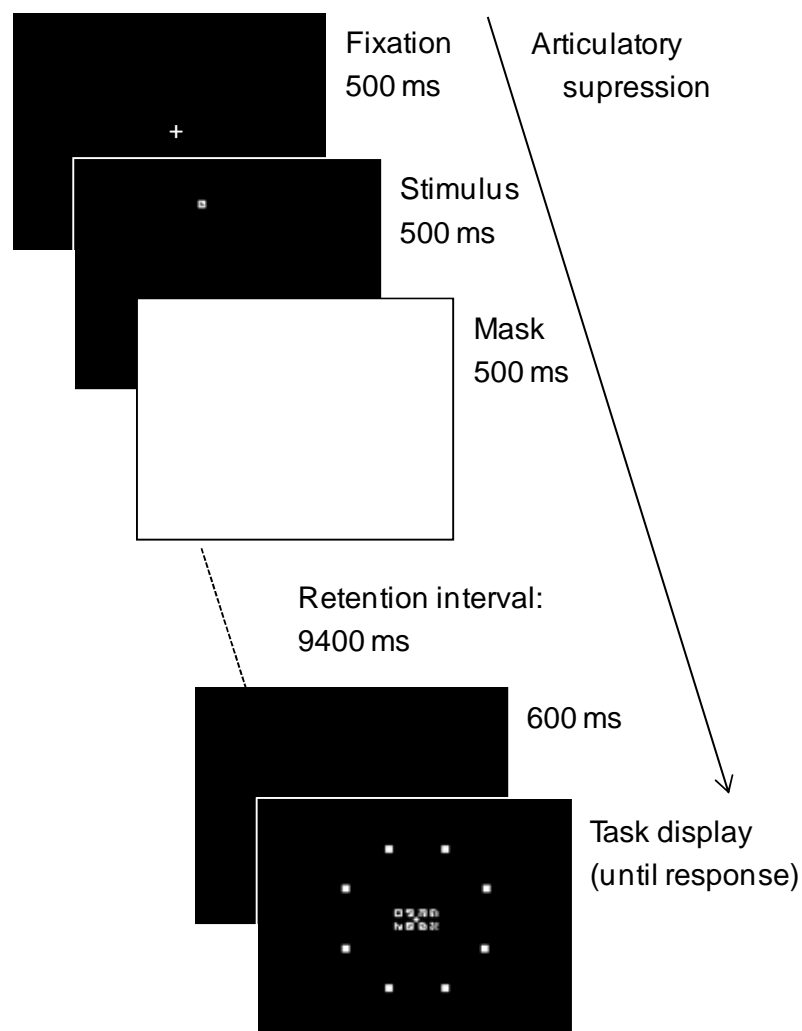


Figure 2.2. Time course of an experimental trial. According to the memory task, participants were required to click on either locations (location-only) or ideographs (object-only), or on both ideograph and its location (object-location).

There were three conditions in the 10 seconds retention interval (Figure 2.3) – two concurrent tasks and a control condition – and a black background screen was displayed in the last 600 ms of the retention interval in order to avoid an abrupt transition to the task display (as depicted in Figure 2.2). In the control condition, a white fixation cross remained for 9.4 s and the participants were instructed to wait for the task display.

In the movement discrimination task (cf. Klauer & Zhao, 2004), the participants had to search for a static stimulus among dynamic distracting stimuli. Ten white asterisks measuring 0.6° of visual angle appeared in random locations in a black background. One asterisk remained static and the others moved 0.02° of visual angle every 100 ms. The asterisks moved in diagonal directions that were randomly defined for each trial of the task. The participants had to find and to click on the static asterisk. After a response, or in case of no response within 5 seconds, a new trial started after a delay of 200 ms.

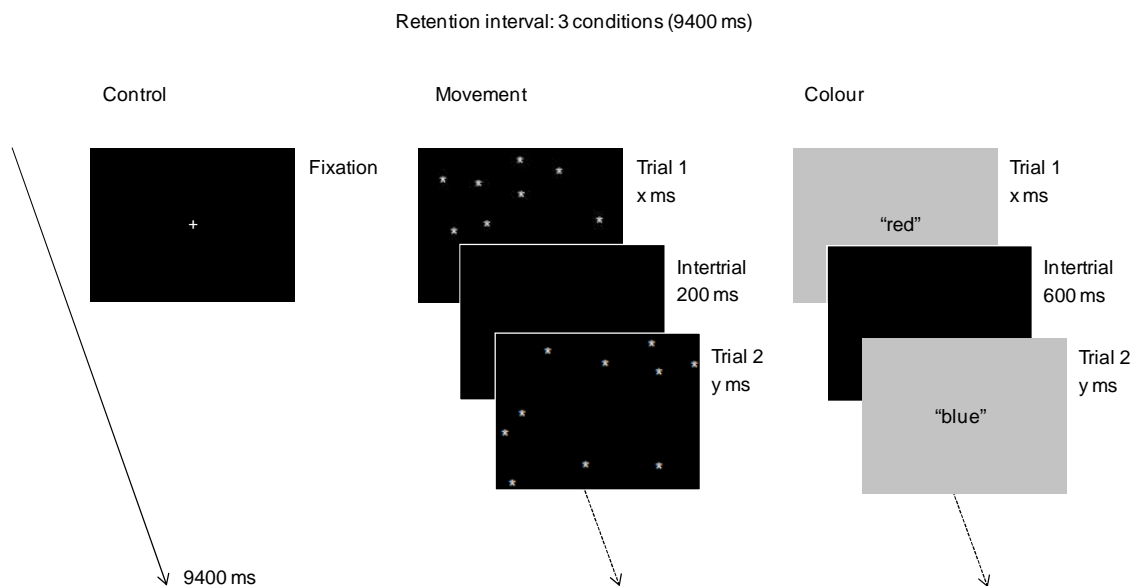


Figure 2.3. Retention interval conditions: 9400 ms were filled either with a fixation screen (control), a series of trials requiring mouse clicks on static asterisks (movement discrimination), or a series of trials requiring red/blue classification (colour discrimination).

In the colour discrimination task, the participants had to judge the colour of a series of monochromatic displays (Klauer & Zhao, 2004). The stimulus pool consisted of 14 colours with the RGB coordinates defined by the following formulae: $R = 47 - 2i$, $B = 13 + 2i$, $G = \min(R, B) \div 3$, where $i = 1, \dots, 16$, $i \neq 8$, $i \neq 9$, and ' \div ' denotes integer division. The colours ranged from dark red to dark blue, with intermediate tones with both red and blue components. Nonetheless, seven colours could be classified as in the red family and seven as in the blue family. For every trial the colours were sampled randomly with replacement. A

trial consisted of a monochromatic display that filled the entire screen, and the participants had to press the left mouse key if the colour was more red than blue and the right mouse key if it was more blue than red. After a response, or in case of no response within 3 seconds, a new trial started after a delay of 600 ms.

Procedure

The participants were individually tested in a dim light room and the entire session required around 50 minutes. The session started with three practice trials for each memory task and five 10 seconds cycles for each concurrent task. The practice blocks were performed in the following order: memory for locations, memory for appearances, memory for both appearance and location, movement discrimination and colour discrimination.

The practice phase was followed by three experimental blocks presented to participants in counterbalanced order. Each block started with six practice trials (two trials per interference condition) followed by 36 experimental trials (i.e., 12 per condition). Within a block, a specific ideograph-location combination appeared only once and the interference conditions were randomized between trials. For this reason, participants were instructed to keep the hand over the mouse during the session. Feedback for memory tasks was provided only for the practice trials, and for both discrimination tasks the PC-speaker emitted a sound in case of incorrect response.

For each memory task, we have computed the participant's percentage of correct responses in each experimental condition (control, colour discrimination, and movement discrimination):

Correct Responses (CR%) = $(x/12) * 100$, where x is the number of correct trials within an experimental condition.

We also computed interference scores, that is, the difference between the control and interference conditions:

Interference Score (%) = CR% (control) - CR% (concurrent task).

2.4 Results

Figure 2.4 (upper panel) shows the mean percentage of correct responses for the location-only and object-only memory tasks in the three retention interval conditions. A first step was to analyse the effects of concurrent tasks on the recall of locations and objects. We performed a two-way repeated measures ANOVA for the factors task (location vs. object) and interference condition (control vs. colour vs. movement), and significant results were further analysed by post hoc comparisons using Bonferroni correction¹. A main effect of task was not observed, $F(1, 17) < 1$, $MSE = 129.28$, $p = .332$, $\eta^2_p = .05$, suggesting that both tasks imposed similar cognitive demands. There was a main effect of interference condition, $F(2, 34) = 32.06$, $MSE = 116.63$, $p < .001$, $\eta^2_p = .65$, and pairwise comparisons with control condition revealed significant effects of movement discrimination ($p < .001$, mean difference = 19.9%, $SE = 2.5$) and colour discrimination ($p = .004$, mean difference = 6.3%, $SE = 1.7$), with movement being more disruptive than colour discrimination ($p = .002$; mean difference = 13.6%, $SE = 3.2$). An interaction effect was also observed, $F(2, 34) = 5.84$, $MSE = 132.09$, $p = .007$, $\eta^2_p = .25$, indicating that concurrent tasks differently affected memory for locations and objects (Figure 2.4, lower panel). Pairwise comparisons revealed that memory for location was significantly impaired by movement discrimination ($p < .001$; mean difference = 25.9%, $SE = 3.5$) but not by colour discrimination ($p = .44$; mean difference = 3.2%, $SE = 2.1$). On the other hand, memory for objects was impaired by both colour ($p = .02$; mean difference = 9.4%, $SE = 3.1$) and movement discrimination ($p = .008$; mean difference = 13.9%, $SE = 3.9$).

Performance in the concurrent tasks, on the other hand, remained unaffected by the memory load (objects or locations), that is, there were not trade-off effects between memory and concurrent tasks. Figure 2.5 shows the mean percentage of correct responses in concurrent tasks according to the memory tasks performed. A two-way repeated measures ANOVA for the factors concurrent task (colour vs. movement) and memory task (location vs. object vs. object-location) revealed no significant effects or interaction, $F < 1$.

¹ The Bonferroni correction used in this thesis multiplies the unadjusted p -values by the number of comparisons, so adjusted p -values are displayed for the chosen significance level α ($\alpha = .05$). This operation is equivalent to divide the significance level (α) by the number of comparisons (n): α/n .

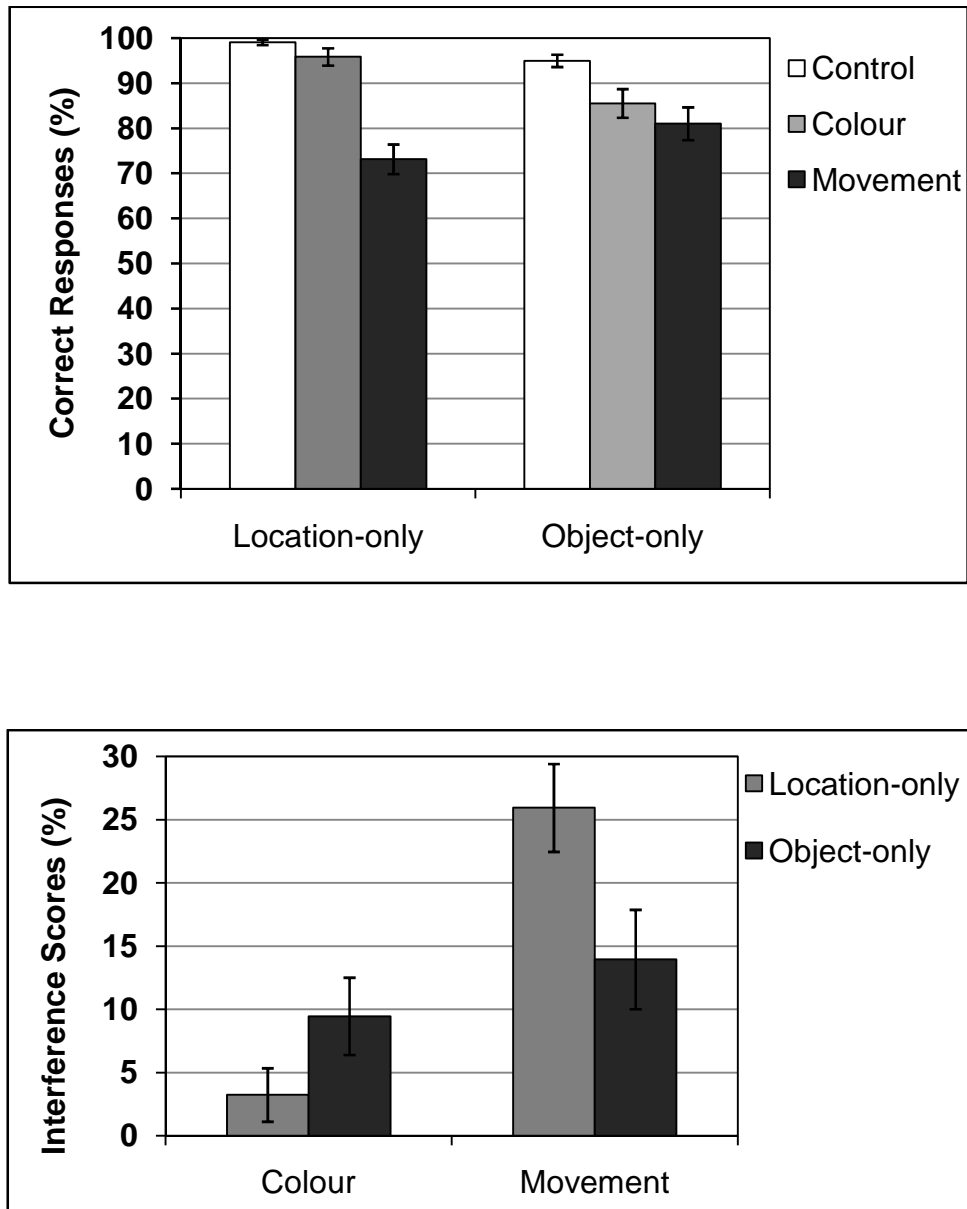


Figure 2.4. Memory task performance for location-only and object-only in each retention interval condition (upper panel), and interference scores for each concurrent task (lower panel). Error bars represent standard errors.

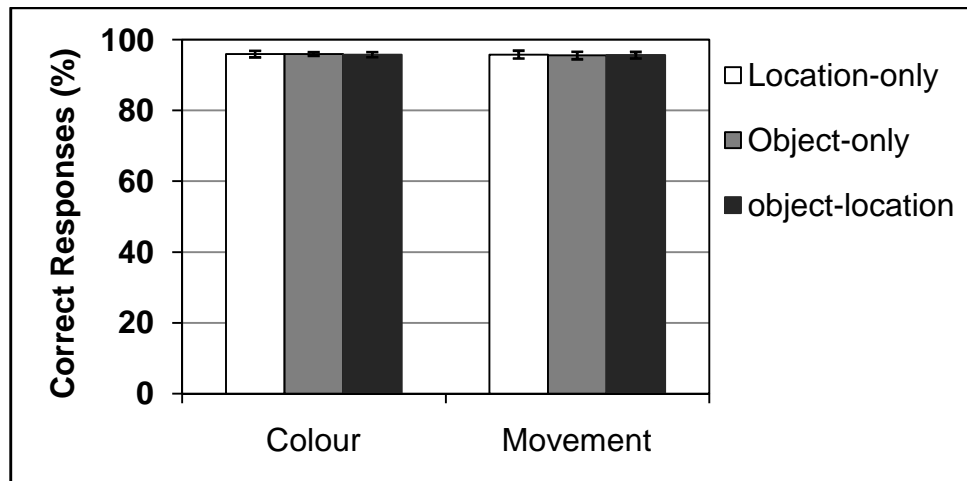


Figure 2.5. Percentage of correct responses in colour discrimination and movement discrimination concurrent tasks for each main memory task. Error bars represent standard errors.

Regarding memory for object-location bindings, we fragmented participants performance in the selection of objects and locations (Figure 2.6, upper panel). A two-way repeated measures ANOVA was carried out for the factors selection (object vs. location) and interference condition (control vs. colour vs. movement). There was no main effect of selection, $F(1, 17) < 1$, $MSE = 93.56$, $p = .472$, $\eta^2_p = .03$, indicating that participants were able to retain both object and its location. A main effect of interference condition was observed, $F(2, 34) = 8.96$, $MSE = 187.32$, $p = .001$, $\eta^2_p = .34$, and pairwise comparisons with the control condition revealed significant effects of movement discrimination ($p = .001$, mean difference = 13.5%, $SE = 3.1$) and colour discrimination ($p = .036$, mean difference = 8.4%, $SE = 3.0$), with both discrimination tasks being equally disruptive ($p = .495$; mean difference = 5.1%, $SE = 3.5$). An interaction effect was also observed, $F(2, 34) = 11.44$, $MSE = 60.54$, $p < .001$, $\eta^2_p = .40$, indicating that selection of objects and locations were differently affected by concurrent tasks (Figure 2.6, lower panel). Pairwise comparisons revealed that object selection was impaired by colour discrimination ($p = .017$; mean difference = 11.7%, $SE = 3.7$) and the effect of movement discrimination approached significance ($p = .058$; mean difference = 8.2%, $SE = 3.16$). Selection of locations, on the other hand, was impaired by movement discrimination ($p < .001$; mean difference = 18.9%, $SE = 3.87$) but not by colour discrimination ($p = .417$; mean difference = 5%, $SE = 3.2$).

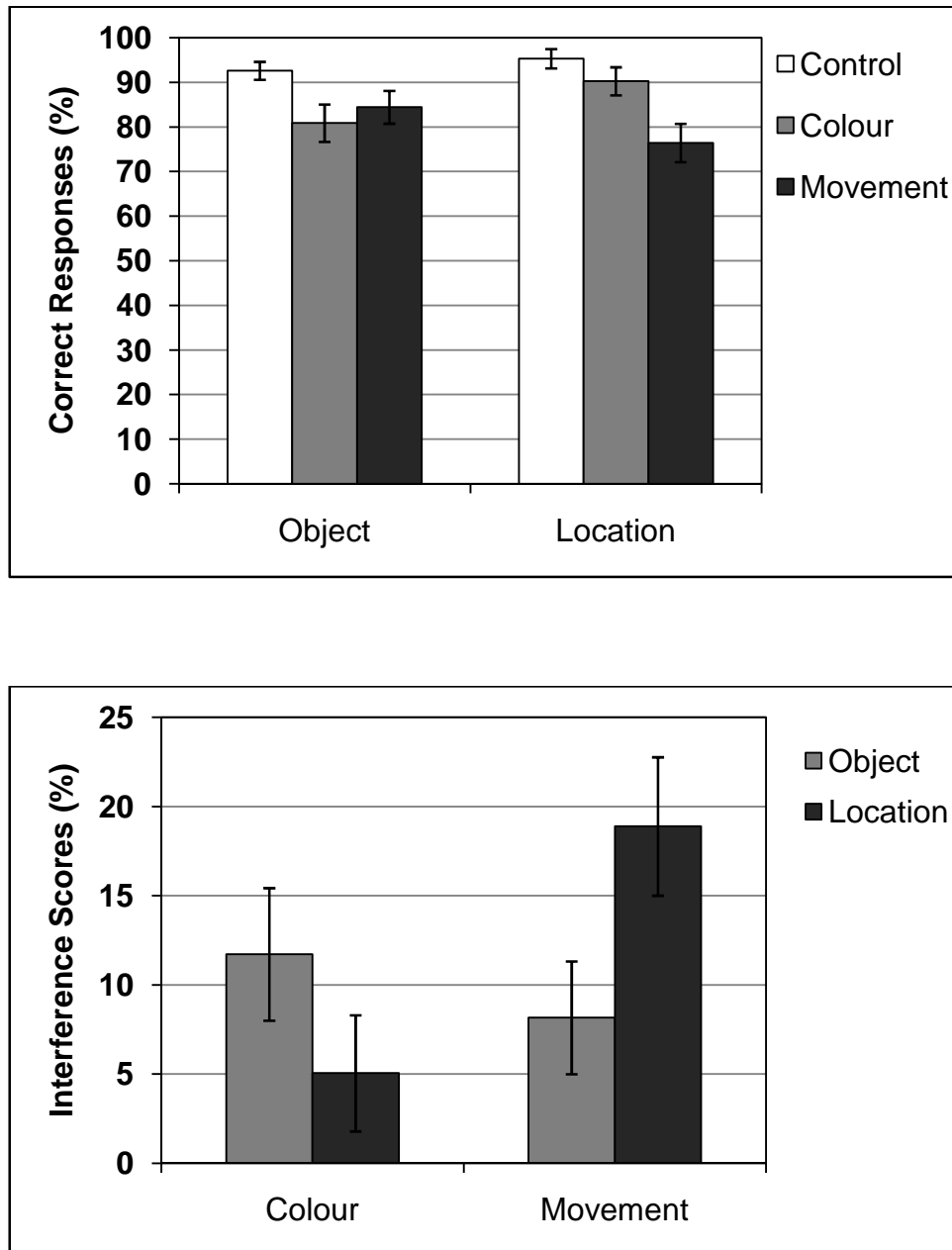


Figure 2.6. Performance in the object-location binding task in each retention interval condition (upper panel), and interference scores for each concurrent task on selection of objects and locations (lower panel). Error bars represent standard errors.

2.5 Discussion

The present study focused at investigating the effects of two concurrent tasks, namely colour and movement discrimination, on the temporary retention of locations, objects and object-location bindings. One aim was to replicate the findings that a visual concurrent task disrupts memory for objects but not for locations, whereas a spatial concurrent task disrupts memory for locations but not for objects, revealing a double dissociation pattern (Klauer & Zhao, 2004). Another aim was to investigate whether concurrent tasks can selectively disrupt the process of binding an object to its location, a result not previously found in the literature (Zimmer et al., 2003).

Our results can be divided into two sets. Regarding working memory for objects and locations, the results fairly replicate the findings of Klauer and Zhao (2004) and are in line with the literature, bringing further support for a dissociation between visual and spatial processes in VSWM (Darling et al., 2007, 2009; Logie & Marchetti, 1991; Tresch et al., 1993). Memory for locations was disrupted by movement discrimination but not by colour discrimination. On the other hand, memory for objects was equally disrupted by both discrimination tasks, a somewhat unexpected result. In Klauer and Zhao (2004) results, although both tasks disrupted memory for objects, the colour task was significantly more disruptive than the movement task. A possible explanation for this discrepancy between studies is that our adaption rendered the task more difficult. In fact, in our study, movement discrimination had a much more disruptive effect than reported by Klauer and Zhao (2004), and its effect may also have an attentional component.

Nevertheless, a clear double dissociation pattern emerged in the interferences produced by concurrent tasks (see Figure 2.4, lower panel), indicating that memory for locations requires spatial cognitive resources also involved in movement discrimination, whereas memory for objects requires visual cognitive resources involved in colour discrimination. Furthermore, these results are not due to trade-offs in cognitive resources used by memory and concurrent tasks, because participants were able to perform concurrent tasks accurately most of the time, in despite of the memory load.

Regarding working memory for object-location bindings, the results mainly replicated what was found for recalling either objects or locations separately. As seen in Figure 2.6 (lower panel), colour discrimination disrupted selection of objects (a drop around 12%) but not of locations (a nonsignificant drop around 5%), whereas movement discrimination disrupted selection of locations (a drop around 19%) but not of objects (an almost significant

drop of 8%). Interestingly, selective interference effects on object-location memory are also clear-cut, suggesting that bound object representations depend upon separate visual and spatial resources of VSWM. This result is in line with an associative view of binding, in which a bound representation results from associative links between different types of features (cf. Elsley & Parmentier, 2009).

The present study therefore has overcome the limitations of Zimmer et al. (2003): Object-location memory relies on both visual and spatial resources, provided that participants have to recognise the visual appearance of a memorised stimulus among other distracting stimuli, as well as to recognise its precise location among the other ones. Furthermore, our procedure was based on briefer stimulus presentation and on faster response times, possibly reducing the contribution of episodic memory processes.

In conclusion, our results support the view that VSWM representations are dependent upon the updating or refreshing of separate features, and therefore support an associative view of object-location binding.

CHAPTER 3

STUDY 2

FORWARD AND BACKWARD RECALL OF LOCATIONS, COLOURS AND COLOUR-LOCATION BINDINGS IN CHILDREN WITH SPECIFIC LEARNING DISABILITIES

3.1 Introduction

Since the pioneering work by Jacobs (1887) and Binet (1903), the immediate serial recall of digits or word lists has been considered a crucial clinical marker of an individual's cognitive functioning, both in general and in developmental age. Tasks in which lists are recalled in reverse order have also been an important assessment tool in psychometric batteries (e.g., Wechsler, 1974, 1991). Only recently, however, attention has been devoted to the forward and backward recall of types of information other than digits or words and this has raised a series of issues. One critical issue has theoretical implications and concerns the cognitive processes underlying the immediate recall of verbal and other types of material. Another critical issue concerns its potential implications to neuropsychological assessment. In the present study, we have addressed both theoretical and applied issues regarding forward and backward recall of visuospatial material, by comparing two samples of children with different learning disabilities to a third group of typically developing children.

Different components of working memory seem to be involved in the recall of verbal information in forward as opposed to backward order. In particular, backward verbal recall relies on additional central executive resources implicated in reversing a retained order, a process that reduces the number of items recalled by comparison with forward recall (Guérard & Saint-Aubin, 2012; Hale, Hoepfner, & Fiorello, 2002; Kessels et al., 2008). This pattern is typically found in children, who rely on executive resources to reverse a verbal sequence, in contrast to adults who may employ other strategies such as the online reversal during encoding (St Clair-Thompson, 2010).

Regarding VSWM, the few researches comparing forward versus backward recall using the Corsi task have generated conflicting results. Some studies have shown that to recall information backwards does not imply a loss of performance with respect to forward recall (Isaacs & Vargha-Khadem, 1989; Kessels et al., 2008; Vandierendonck & Szmalec, 2004; Wilde & Strauss, 2002). Moreover, in the extensive study by Wilde and Strauss (Wilde & Strauss, 2002), about one third of the sample had a better performance on backward compared to forward recall, leading the authors to cast doubts on both theoretical and clinical implications of the Corsi test. These findings support the idea that the backward Corsi is not the spatial analogue of the backward Digit Span, that is, there are no evidences of an involvement of additional central executive resources. In favour of this view, it has been also observed that intellectually disabled children and adolescents who did badly in both verbal and visuospatial working memory tasks that depended on central executive resources had a

normal performance in sequential VSWM tasks (Lanfranchi, Carretti, Spanò, & Cornoldi, 2009). In a study examining memory and event-related potentials elicited in recognition tasks involving either digits or blocks, Nulsen, Fox and Hammond (2010) found that reversing item order reduced both memory performance and the amplitude of the P3a and P3b event-related potentials in verbal, but not in visuospatial tasks.

Considering everyday life problems, the backward recall of visuospatial information may be crucial in situations when one has to find the way back to a starting point or has to search for previously seen objects, two aspects which appear to be impaired in persons with a deficit in VSWM (Cornoldi et al., 1995). Indeed, some studies have shown that specific populations may have an impaired backward spatial span, such as adults with low visuospatial abilities and children with nonverbal learning disabilities (Cornoldi & Mammarella, 2008; I. C. Mammarella & Cornoldi, 2005b). Thus, the backward Corsi seems to tap on specific working memory resources that are impaired in individuals with visuospatial deficits, something that is not apparent in other working memory tasks such as the forward Corsi or the Digit Span. These findings show the potential of the Corsi test to discriminate clinical groups with visuospatial deficits, such as children with specific learning disabilities.

This issue can be extended to other situations if we consider that VSWM is also involved in the recall of other features of a visual display, such as configurations, colours, shapes, orientation, and so on (Cornoldi & Vecchi, 2003; Logie, 1995). There are theoretical reasons to expect that direction of recall for visual features may involve different processes in respect to recall of locations. Research on working memory functional structure and organisation has provided converging evidence that VSWM is not a unitary system, but can be further fractionated in different spatial and visual subsystems (Baddeley, 2007; Cornoldi & Vecchi, 2003; Klauer & Zhao, 2004; Logie, 1995, 2011).

In short, theoretical accounts of how VSWM is organized would benefit from a more systematic investigation into the forward vs. backward dissociation in the VSWM domain. On the other hand, both direction of recall and binding processes in working memory may have potential implications to neuropsychological assessment.

3.2 Objectives and hypotheses

The present study examined to what extent two different populations with learning disabilities (LD), both hypothesized to have working memory problems, could have specific

deficits in VSWM tasks. In particular, our study intended to examine the implications of backward recall and memory binding, two aspects that have never been systematically studied in individuals with LD. We have tested three groups of children – one with nonverbal learning disability (NLD), one with dyslexia, and one with a typical development (TD) – using three different VSWM tasks involving forward and backward recall. We have opted to use the classical Corsi blocks task to measure the spatial working memory component. To assess visual processes, we have adopted a task that involved the forward and backward recall of colours in the same format as the Corsi task, that is, participants were asked to choose between different colours and then orderly reconstruct their presentation (Hitch, Halliday, Schaafstal, & Schraagen, 1988). Memory for colours seems to be a good way to assess working memory components separately from spatial components. Administering a colour recall task is also one of the best methods for assessing memory binding by asking participants to memorize locations and colours concurrently. In general, memory for colours seems to involve visual working memory and it has been reported that, in working memory tasks requiring the recall of visual information, children of the same age as those considered in the present study may also use verbal codes to support visual memory of nameable visual stimuli such as colours and familiar objects (Henry, Messer, Luger-Klein, & Crane, 2012; Hitch et al., 1988; Palmer, 2000).

Based on previous literature, we expected that children with NLD would have worse VSWM performance than children with typical development. Furthermore, children with dyslexia were not expected to have serious impairment in VSWM. Regarding memory for locations, we predicted that the NLD group would perform less well in the Corsi task than the other two groups, specifically in backward recall. Concerning memory for colours, we also predicted a poor performance of the NLD group, mostly due a VSWM-related impairment as suggested by the literature. Detailed predictions regarding group differences and direction of recall, however, were not possible since systematic research on direction of recall are not available for the visual domain. As for the binding task, both groups of children with LD were expected to have difficulties in the binding task (Jarrod et al., 2007). Furthermore, if the processes involved in concurrently remembering colours and locations demand both the skills needed to remember the two types of information separately, then children with NLD should have particular difficulty in backward recall. On the other hand, if memory binding involves different processes, then the weaknesses seen in children with LD with the separate recall of locations and colours would not be necessarily extended to the case of binding.

3.3 Method

Participants

Fifteen children with a diagnosis of NLD (5 girls and 10 boys, mean age = 100.5 months, $SD = 7.3$), 15 with dyslexia (9 girls and 6 boys; mean age = 101.7 months, $SD = 8.1$) and 15 with typical development (TD) (7 girls and 8 boys; mean age = 105.9 months, $SD = 11.6$), mostly attending 3rd or 4th grades of primary school in small Italian towns (age range from 8 to 10 years-old). The groups did not differ according to age, $F(2, 42) = 1.43, p = .25$, or to gender distribution, $\chi^2(df = 2) = 2.14, p = .34$. All children spoke Italian as their first language and none were visually or hearing impaired. No participant received diagnosis of developmental coordination disorder or neuropsychological impairments. A signed informed consent form was obtained from the participants' parents. This research followed the Ethical Principles of the Declaration of Helsinki and the Deontological Code of the Italian Order of Psychologists.

We ensured that children met specific criteria during group selection. General verbal and visuospatial abilities were assessed using the Verbal Meaning and Spatial Relations subtests of the Primary Mental Ability Test (PMA) (Thurstone & Thurstone, 1963, 1985). Visuospatial constructional abilities were tested using Rey's Complex Figure Test (1941, 1968) asking the child to copy a complex drawing. Reading decoding (speed and accuracy) was assessed with a lexical decision task (Caldarola, Perini, & Cornoldi, 2012) and a pseudoword reading task (derived from Sartori, Job, & Tressoldi, 2007). Finally, the children were also identified on the basis of difficulties detected by their teachers using the Shortened Visuospatial Questionnaire (SVS) (Cornoldi et al., 2003). The SVS is a tool developed in Italy and Scotland to identify children with NLD – teachers have to judge if a child has a given characteristic on a four-point scale. The SVS generates a visuospatial score (range 10–40) based on 10 items with a demonstrated sensitivity in detecting some of the deficits that represent crucial features of NLD (Cornoldi et al., 2003). The questionnaire includes an item enabling teachers to estimate the child's socio-cultural level, and children referred to as having a very low socio-cultural level were not included in our sample.

All children with NLD scored around 1.5 SD below in the Spatial Relations subtest of the PMA ($M = 8.05, SD = 4.1$)², had visuospatial scores in the SVS questionnaire lower than

² Means (M) and standard deviations (SD) of the lexical decision task (Caldarola, Perini, & Cornoldi, 2011), the Verbal Meaning and Spatial Relations of the Primary Mental Ability Test (Thurstone & Thurstone, 1963, 1985) were derived from a sample of 351 children of the same age range of those considered in the present study.

the 15th percentile, a very poor performance in Rey's Complex Figure test, and average scores in the Verbal Meaning subtest of the PMA ($M = 10.09$, $SD = 3.9$), in the lexical decision task ($M = 0.11$, $SD = 1.3$) and in pseudoword reading. All children with dyslexia had scores around 1.5 SD below in the lexical decision task, impaired pseudoword reading, and average scores in both the Spatial Relations and Verbal Meaning subtests of the PMA, as well as average scores in the Rey's Complex Figure Test and in the visuospatial index of the SVS questionnaire. As a control group, children with TD had average scores in all the above-mentioned tasks. Table 3.1 summarizes the descriptive statistics for the children's performance by group (NLD, dyslexia and TD) and the results of group comparisons based on one-way ANOVA and pair-wise comparisons with Bonferroni's correction at $p < .05$.

Table 3.1

Mean Scores and Standard Deviations for the Three Groups in the PMA Subtests (Spatial and Verbal), the Lexical Decision and Pseudoword Reading Tests, the SVS Index and the Rey Complex Figure Test

Test	TD	dyslexia	NLD	One-way ANOVA	
	<i>M</i> (<i>SD</i>)	<i>M</i> (<i>SD</i>)	<i>M</i> (<i>SD</i>)	<i>F</i> (2, 42)	Bonferroni post hoc ^a
PMA-spatial	9.7 (2.8)	9.0 (2.6)	3.0 (0.7)	39.99***	NLD < dys; NLD < TD
PMA-verbal	10.7 (2.6)	9.0 (2.7)	9.3 (3.0)	1.54	ns
Lexical decision	-0.14 (.56)	-1.56 (.45)	0.16 (.74)	36.11***	dys < TD; dys < NLD
Pseudoword reading	63.4 (13.1)	86.9 (20.0)	65.3 (16.3)	9.07***	dys > TD; dys > NLD
SVS	32.0 (9.8)	30.9 (8.1)	22.2 (7.4)	6.04**	NLD < TD; NLD < dys
Rey	31.2 (3.0)	27.9 (6.4)	19.7 (7.5)	14.68***	NLD < TD; NLD < dys

Note. PMA, SVS, and Rey are raw scores. Lexical decision are z-scores. Pseudoword reading is time in seconds.

TD = typical development; dys = dyslexia; NLD = nonverbal learning disability; ns = non-significant.

^a Only significant pairwise comparisons are given.

*** $p < .001$. ** $p < .01$

Experimental materials and Procedure

We used a laptop computer with a 15-inch LCD screen and all the experimental procedures were programmed with the E-Prime software (W Schneider et al., 2002). Participants were tested individually in a quiet room. The child sat in front of the computer screen and the experimenter sat to the right of the child to manage the trial presentation and the mouse. In these computerised tests, the children had to indicate their response on the screen, and the experimenter entered the data with the mouse.

The scheme for presenting the stimuli was similar for all the tests conducted in the present study. The basic screen (i.e., the Corsi display) consisted of nine 3 x 3 cm grey squares against a white background, arranged to keep the same proportions and distances as in the original version of the Corsi blocks task (Corsi, 1972; B. Milner, 1971). The experimenter pressed the spacebar to start the trial, the Corsi display remained static for 1200 ms and then a sequence of squares was shown (Figure 3.1). Each square was highlighted by a change of colour for 1000 ms, with an inter-stimulus interval of 500 ms. Within a given sequence, each square became a different colour, and there were six possible colours, namely, black, green, purple, red, turquoise, and yellow, with the following RGB coordinates, respectively: (0, 0, 0), (0, 255, 0), (255, 0, 255), (255, 0, 0), (0, 255, 255), and (255, 255, 0). The end of a sequence was marked by a rectangular frame appearing around the Corsi display for 500 ms, followed immediately by the task display, which varied according to the task (Figure 3.1).

Corsi task: the Corsi display with the nine grey squares was shown on the screen and participants completed the standard Corsi task – they were asked to indicate the locations of sequences of squares that had been highlighted, in the order in which they had been presented (forward version) or in reverse order (backward version). The sequences included from two to six squares, and two trials were administered for each sequence length.

Colour task: the Corsi display disappeared and the six possible colours appeared at the bottom of the screen (from left to right: turquoise, red, purple, yellow, black, and green). Participants were asked to recall the colours in their order of presentation (or reversing this order in the backward version). The sequences contained from two to five colours, and two trials were administered for each sequence length.

Colour-location binding task: the Corsi display remained on the screen and the six colours appeared at the bottom. Participants were asked to indicate first the colour and then its location. For example, in the forward recall they had to indicate the first colour and the first block, then the second colour and the second block, and so on. The sequences presented contained from two to five items, and two trials were administered for each sequence length.

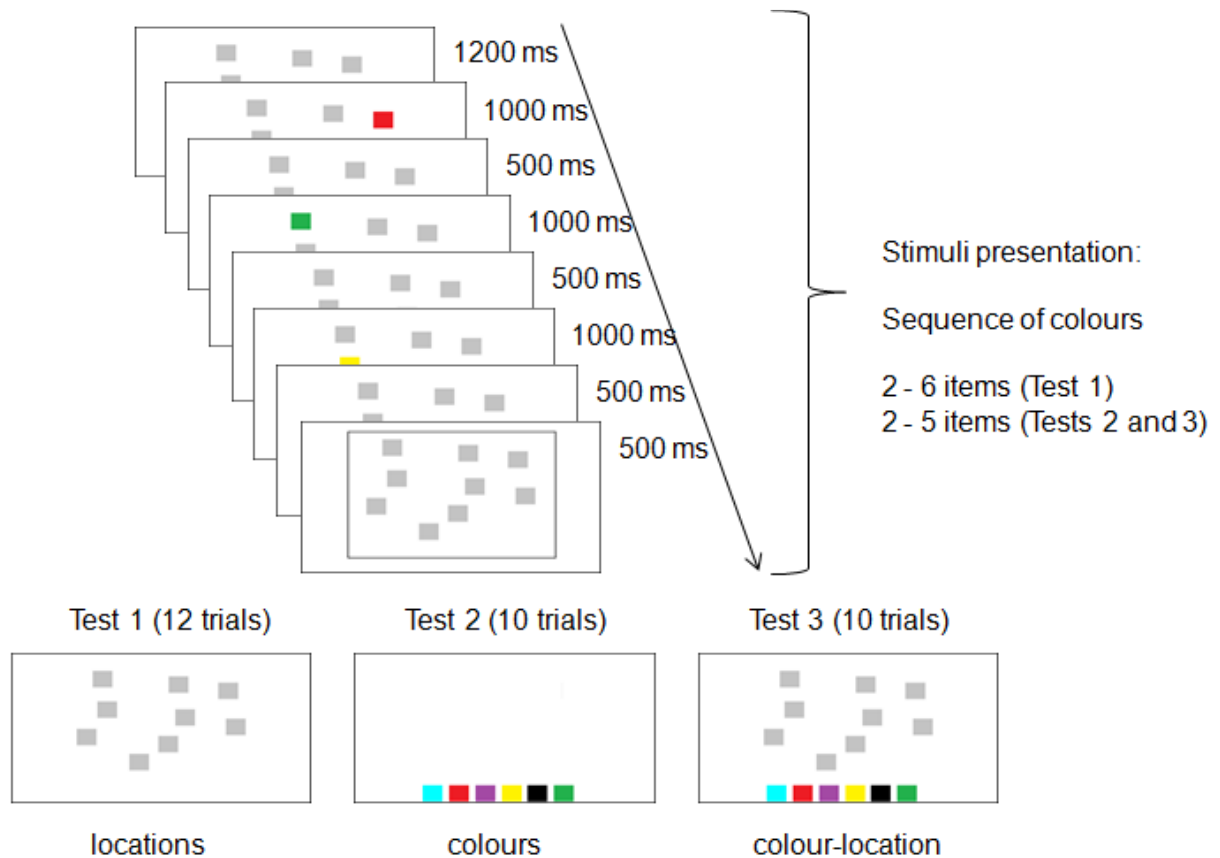


Figure 3.1. Schematic of the experimental protocol. A sequence of colours was presented for memorisation and then participants were required to indicate the order (forward version) or the reverse order (backward version) of locations (Test 1), colours (Test 2) and colour-location bindings (Test 3).

A pilot study with a random sample of children was carried out to investigate different stimuli sets (six different colours vs. one colour in six tones varying along lightness-darkness) and how children would perform the unexplored Colour and Binding tasks. It was observed that performance was very low with colour tones and that the Binding task was very difficult in comparison with the others. Thus, we opted for using six different colours and to present the tasks in increasing order of difficulty.

For each task and recall condition, all the participants performed all the trials for each sequence length (see Appendix C, and tables C.1 and C.2 for the list of trials). The tasks were administered in a way to avoid children getting confused by changing between forward and backward recall, or by randomly changing between memory tasks. In particular, direction of recall was blocked and counterbalanced (Cornoldi & Mammarella, 2008; see I. C. Mammarella & Cornoldi, 2005b). For each group, half of the participants started the session performing the forward recall for all the tasks, and the other half started by the backward tasks. For each block, the tasks were administered in the following order: location, colour, and

colour-location binding. To ensure that the children had understood the task to be performed, there were instructions and practice trials at the beginning of each task. The entire session had a duration around 35-40 minutes: Each Corsi and Colour tasks had a duration around 5 minutes, and the binding task took around 7-10 minutes.

We computed the *order score* for each trial, given by the percentage of items recalled in the right order, which is a more sensitive measure than the typical span based on the number of sequences recalled correctly (see Fischer, 2001; Vandierendonck, Kemps, Fastame, & Szmalec, 2004). For example, the sequence of blocks "5-2-4-3-1" recalled as "5-4-2-3-1" has two serial order errors (i.e., the swap between blocks '2' and '4') and receives a score of 60% ($= 3/5 \times 100$). Regarding the binding task, both colour and location should have been recalled in the correct order to count as a correct item, and the score resulted from the percentage of colour-location bindings recalled correctly in a sequence. For example, in a hypothetical situation in which a participant correctly recalls two colour-location bindings across all sequence lengths, the average score is 64.2%; in a worst scenario in which only one binding is recalled correctly per sequence length, the average score is 32.1%, which is assumed to be the floor level performance for this task.

3.4 Results

Preliminary analyses indicated that age and gender did not have significant effects on scores or interactions with group and other variables such as task and recall, so these variables were not further considered. In addition, since half of participants started by forward and the other half by backward recall, a mixed ANOVA was conducted with order of forward/backward tasks as a covariate factor. No effect of presentation order was observed, indicating that practice in one recall condition did not affect the performance in the other condition. Table 3.2 shows the mean percentage of correct responses, with the standard deviations and confidence intervals (95% CI), for forward and backward recall in the three VSWM tasks for each group of children. Figure 3.2 shows graphical representations of group performances for each memory task and recall condition.

Table 3.2

Mean percentages (M) of correct responses, with standard deviations (SD) and confidence intervals (95% CI) in the Corsi, Colour and Binding VSWM tasks, for each group of children

Task	Version	TD		dyslexia		NLD	
		M (SD)	95% CI	M (SD)	95% CI	M (SD)	95% CI
Corsi	Forward	77.7 (12.1)	[71.0, 84.4]	71.7 (12.9)	[64.6, 78.9]	69.3 (14.0)	[61.6, 77.1]
	Backward	83.7 (11.9)	[77.1, 90.3]	78.2 (13.5)	[70.7, 85.7]	61.3 (16.0)	[52.5, 70.2]
Colour	Forward	80.2 (9.3)	[75.1, 85.3]	66.7 (22.9)	[54.0, 79.4]	70.0 (18.4)	[59.8, 80.2]
	Backward	66.3 (13.2)	[59.0, 73.6]	60.9 (16.7)	[51.6, 70.1]	50.7 (15.5)	[42.2, 59.3]
Binding	Forward	55.6 (14.2)	[47.7, 63.5]	48.3 (21.3)	[36.5, 60.1]	48.3 (13.2)	[41.0, 55.7]
	Backward	56.7 (10.9)	[50.7, 62.8]	47.1 (19.0)	[36.5, 57.6]	46.2 (14.2)	[38.4, 54.0]

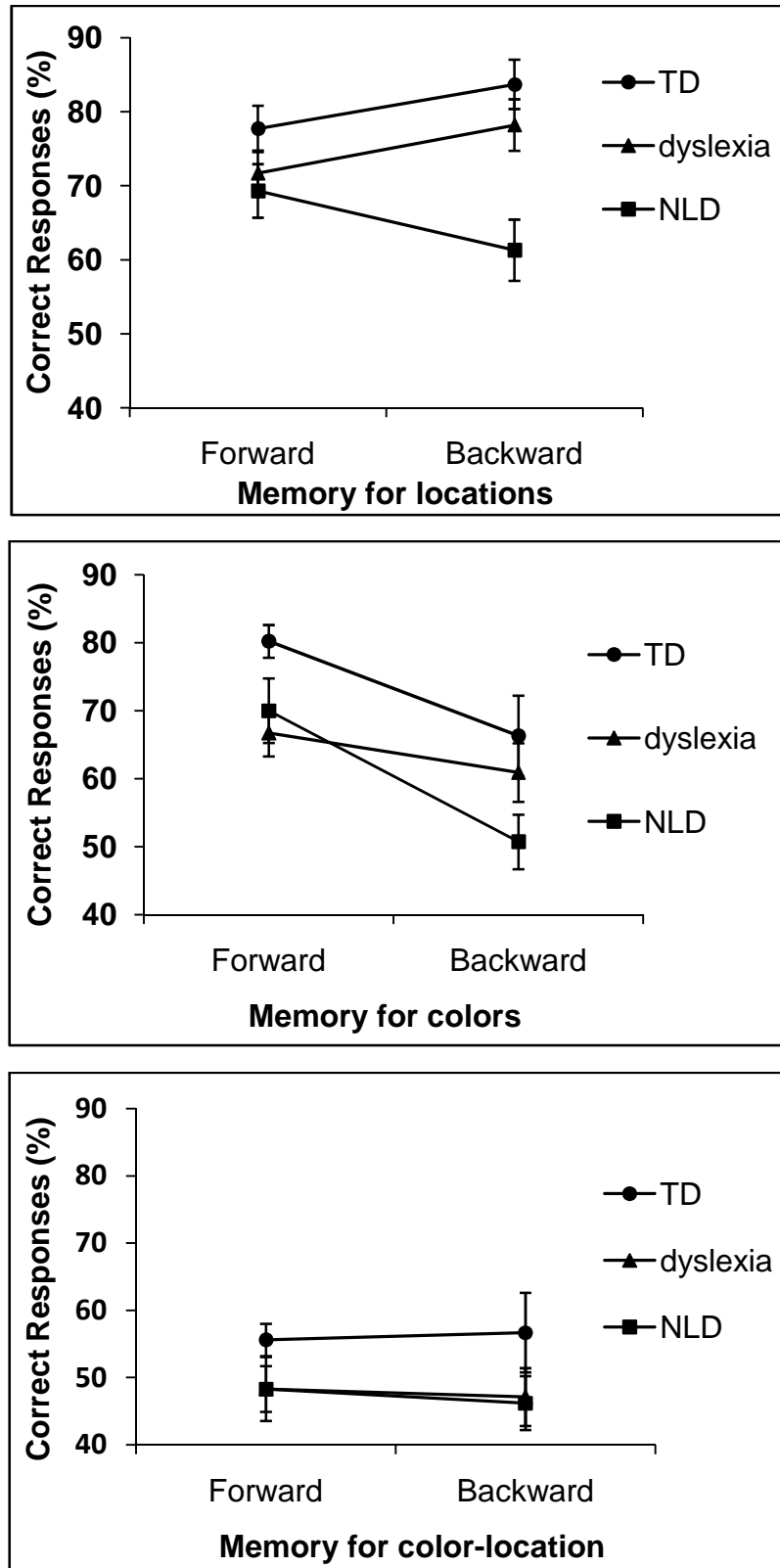


Figure 3.2. Performance for each group of children in forward and backward recall of locations (upper panel), colours (middle panel) and colour-location bindings (lower panel). Error bars represent standard errors.

Statistical analyses

In the following analyses of variance, the significance level was set at .05, the effect size indicator is the partial eta-squared (η^2_p), and the post hoc test using the Bonferroni correction was applied as necessary.

We performed a 3 group (TD vs. dyslexia vs. NLD) x 3 task (Corsi vs. colour vs. binding) x 2 recall (forward vs. backward) mixed ANOVA with group as the between-subjects factor, and the within-subjects factors of task and recall. A main effect of group was observed, $F(2, 42) = 4.78$, $MSE = 740$, $p = .013$, $\eta^2_p = .19$, and the post hoc test revealed a major discrepancy ($p = .012$) between the groups TD ($M = 70\%$) and NLD ($M = 58\%$), whereas the dyslexic group ($M = 62\%$) did not significantly differ from the others. We also observed a main effect of task, $F(2, 84) = 81.00$, $MSE = 156$, $p < .001$, $\eta^2_p = .66$, and post hoc comparisons revealed significant discrepancies ($p < .001$) between all the tasks – performance in the Colour task ($M = 66\%$) was worse than in the Corsi task ($M = 74\%$) and better than in the Binding task ($M = 50\%$). A main effect of recall was also observed, $F(1, 42) = 8.14$, $MSE = 139$, $p = .007$, $\eta^2_p = .16$, resulting from a better performance in forward ($M = 65\%$) than in backward recall ($M = 61\%$). The factors task and recall had a significant interaction, $F(2, 84) = 12.27$, $MSE = 111$, $p < .001$, $\eta^2_p = .23$, and only for the Colour task a discrepancy ($p < .001$) was observed between forward ($M = 72\%$) and backward recall ($M = 59\%$). Direction of recall also interacted with group, $F(2, 42) = 4.11$, $MSE = 139$, $p = .023$, $\eta^2_p = .16$. Post hoc comparisons revealed a significant discrepancy ($p = .005$) between forward and backward recall in the NLD group ($M = 63\%$ vs. $M = 53\%$), but not in the TD (71% vs. 69%) or in the dyslexic group (62% vs. 62%). The NLD group had a significantly worse backward recall than the TD ($p = .008$), but there were no significant differences between groups in forward recall. No significant interactions were observed between the factors group and task ($p = .32$, $\eta^2_p = .05$) or between all the three factors ($p = .22$, $\eta^2_p = .06$).

As can be noticed in the results described, the cognitive requirements of the tasks varied and group differences emerged. Children with NLD performed poorly than controls with TD in the VSWM tasks, especially when backward recall was required. The interaction between the factors group and recall might suggest a specific impairment in backward recall in children with NLD. As can be seen in Table 3.2 and Figure 3.2, however, a major forward-backward discrepancy also emerged for the TD group in the Colour task, and for the Binding task no recall or group discrepancies were observed. To have a better understanding of group differences and direction of recall, further statistical analyses were performed separately for each test.

A 3 group x 2 recall mixed ANOVA on the Corsi scores revealed a main effect of group, $F(2, 42) = 6.55$, $MSE = 276.3$, $p = .003$, $\eta^2_p = .24$. The post hoc test showed that the NLD children's overall performance ($M = 65\%$) was worse than ($p = .003$) the TD group's ($M = 83\%$), but did not significantly differ ($p = .09$) from that of the children with dyslexia ($M = 75\%$). The main effect of recall was not significant, $F(1, 42) < 1$, $p = .50$, $MSE = 87.1$, $\eta^2_p = .01$, and a significant interaction was observed, $F(2, 42) = 5.79$, $MSE = 87.1$, $p = .006$, $\eta^2_p = .22$. Post hoc comparisons revealed that the NLD group had a significantly worse backward recall than both TD ($p < .001$) and dyslexic children ($p = .016$), but the group differences in the forward version were not significant.

A 3 x 2 mixed ANOVA on the Colour task scores showed a main effect of group, $F(2, 42) = 3.42$, $MSE = 391.1$, $p = .042$, $\eta^2_p = .14$. The post hoc test showed that TD group's performance ($M = 74\%$) was better than ($p = .046$) the NLD group's ($M = 60\%$) and did not differ ($p = .21$) from the dyslexic group's ($M = 64\%$). The main effect of recall was significant, $F(1, 42) = 24.45$, $MSE = 155.5$, $p < .001$, $\eta^2_p = .37$, indicating that backward recall was more difficult than forward recall, and the interaction was not significant, $F(2, 42) = 2.19$, $MSE = 155.5$, $p = .12$, $\eta^2_p = .09$. However, the effect-size of .09 indicates the presence of variance across groups and direction of recall. As can be seen in Table 3.2, differences of around 14% and 19% between forward and backward recall, as well as dissociated 95% confidence intervals (CIs), were observed in the groups TD and NLD, but in the dyslexic group the difference was around 6% and the 95% CIs overlapped. Moreover, the backward score of the NLD group falls outside the 95% CIs of the TD group, what might suggest an impairment in backward recall. However, this is a different pattern from the Corsi task, since both TD and NLD groups had a poorer performance in backward recall. The NLD group seems to have had a general difficult in the Colour task, with a drop of 10% in the forward recall in comparison to the TD group, and a drop of 16% in the backward recall.

A 3 x 2 mixed ANOVA on the scores obtained in the binding task showed no main effect of group, $F(2, 42) = 1.96$, $MSE = 384.9$, $p = .15$, $\eta^2_p = .09$, or recall version, $F(1, 42) < 1$, $MSE = 119.1$, $p = .74$, nor any interaction, $F(2, 42) < 1$, $MSE = 119.1$, $p = .83$. Thus, given the requirement of recalling colours and locations concurrently, the effects observed in memory for single features are no more observable. Although no reliable statistical effect was found, it should be noted in Table 3.2 that the lower 95% CIs for both clinical groups are closer to a floor effect. As expected, this indicates that some children with dyslexia and NLD had difficulties in the binding task.

3.5 Discussion

This study focused on the processes involved in performing three different VSWM tasks by testing forward and backward recall of locations, colours, and colour-location bindings in children with two different types of learning disability (NLD and dyslexia) and in controls with TD. Our aim was to ascertain whether children with LD have difficulties in such tasks, and whether their performance can shed light on the processes involved in different VSWM tasks.

Our results showed that children with LD have difficulty in the immediate recall of locations and colours; these difficulties differ to some degree between children with NLD and with dyslexia. As expected, children with dyslexia had no significant impairment in the VSWM tasks by comparison with controls, although their performance in the colour and binding tasks was generally poorer and closer to the NLD group. It must be noticed that children of this age may take advantage from verbal recoding of some stimuli and from verbal rehearsal strategies to support visual working memory (Gathercole & Pickering, 2000; Gathercole, 1998; Henry et al., 2012; Hitch et al., 1988; Pickering et al., 2001). However, given the language-related problems of children with dyslexia, this group difficulty in the colour task may be partially attributable to their finding it more difficult to use adequate verbalization strategies. In other words, the reduced use of phonological recoding and rehearsal (Henry et al., 2012; Palmer, 2000) may also have reduced the need for reverting the sequence of information. Since only the dyslexic group showed a similar performance in the forward and backward recall of colours (with a difference of only 6%, see Table 3.2, Figure 3.2, middle panel), our view is that it reflects a strategy more reliant on VSWM resources. The other two groups are more likely to have used verbal working memory resources to support VSWM, because the decay in their backward recall performance resembled the typical effect seen in verbal working memory tasks such as the Digit Span.

As predicted, children with NLD have significant impairments in memory for locations and colours, but the expected impairment in colour-location binding was not observed. Our results further support observations regarding spatial processes and VSWM difficulties in children with NLD (Cornoldi et al., 1999, 1995; I. C. Mammarella & Cornoldi, 2005b), and extend these findings to the case of memory for colours. Moreover, it is worth noting that backward spatial recall posed specific difficulties for children with NLD, offering further support that this is a specific deficit of these children and that this task may be used to discriminate this LD population (I. C. Mammarella & Cornoldi, 2005b). This impairment may

be related to a symptom often reported in children with NLD – the fact that they easily get lost and are unable to find their way back (Cornoldi et al., 1995). Our view is that the backward Corsi task requires specific spatial processes, possibly of a spatial-simultaneous nature (see Cornoldi & Mammarella, 2008; I. C. Mammarella & Cornoldi, 2005b). By using spatial-simultaneous processes, which should be preserved in children with dyslexia and with TD, the sequence of blocks is codified and retained as an overall pattern of locations, that is, a simultaneous mental representation of the pathway as a whole, and recall is facilitated by starting from the last item. Children with NLD, given their low visuospatial abilities and VSWM, could have problems in constructing and retaining such mental representation of a pathway. The forward Corsi task, on the other hand, is reliant on spatial-sequential processes given that the retrieval process should mimic the stimuli presentation, that is, the pathway should be recalled in the same order it has been codified. The difficulty that children with NLD had in backward recall was also apparent in the Colour task, but was not specific to them in this case, as it was also seen in children with TD.

Taken together, these results confirm the importance of assessing both forward and backward recall of visuospatial information. Backward recall in VSWM tasks did not always reflect the typical pattern of results seen in the recollection of verbal information (i.e., a decline in performance with respect to forward recall). The dyslexic group showed no significant deterioration in their performance in the Colour task; and all three groups had a similar performance in both recall versions in the Colour-location binding task. In the Corsi task, both the TD controls and the children with dyslexia did better in the backward recall than in the forward recall, a pattern already reported in the literature (Wilde & Strauss, 2002). This means that the general assumption concerning backward verbal span – that people first store the sequence in forward order and then have to reverse its order, with a high cost for their performance – may not apply to all VSWM span tasks.

Regarding the colour-location binding task, the patterns seen in the Corsi and the Colour task were no longer present when the two features had to be recalled together. No particular VSWM difficulties were apparent in the groups with LD, neither of which differed from the group with TD. This specific pattern might suggest that specific processes are involved in binding spatial and colour information. This may be also related to our general finding that the VSWM problems in children with LD are specific, not general. In fact, the LD groups' different patterns relating to the direction of recall were not seen in the colour-location binding task, meaning that binding location and colour implicates different processes from those involved in recalling either location (as tested in the Corsi task) or colour (as

tested in the Colour task). Although the children's performance did not reach a floor effect, the task may have had an insufficient discriminatory power, that is, it was a difficult task for all the children regardless their neuropsychological profile.

In sum, our findings contribute to the understanding of how VSWM is organized and of the distinctive characteristics of children with different learning disorders, also revealing clinical and everyday life applications. From a general point of view, our results show that different processes are implicated in tasks requiring the recall of locations or colours, and combinations of the two. These processes are presumably partly related to the functioning of the spatial and visual components of VSWM, respectively, coupled to a mechanism devoted to encoding and retaining bound information. The organisation of VSWM should be further defined to take into account the specific patterns seen in backward spatial recall, distinguishing between a spatial-sequential process involved in the forward recall of locations and a spatial-simultaneous process needed for backward recall. In fact, our results suggest that backward recall performance was not the result of maintaining the forward order of the sequence and then reversing it (which is what happens for verbal information). Our findings will need to be confirmed and extended, however, because our study necessarily had a number of limitations that would have to be carefully tested in future research. One of its main limitations concerns the choice of tasks, which only represent a sample of the domains considered in the study. For instance, for the purposes of the present study, we had to devise new adaptations of tasks assessing VSWM, and the psychometric properties of these tasks are not known. This is a problem that always exists when new issues are examined, and is particularly critical for the colour-location binding task, in which no clear group effects were found. Another problem concerns the colour recall task, which presumably involves other processes as well as visual working memory. We used this procedure because a pilot study had shown that manipulations to reduce the participant's use of phonological recoding (such as using colours with the same verbal label, or articulatory suppression) tended to disrupt the child's performance to such a degree that it dropped to the chance level, but we increased the likelihood of children also use verbal strategies as a result. In fact, when children were interviewed informally after the experiment, some of them clearly reported having used verbalizations; this is an aspect that could be assessed more systematically in future research.

Finally, the present study emphasized the importance of examining both forward and backward recall of visual and spatial information, presented separately and bound together, and of considering their implications when assessing the difficulties encountered in learning-disabled children. In particular, this study generated further information on a specific deficit

in children with NLD (a worse performance in backward than in forward Corsi). Our results also revealed that the processes involved in binding colours and locations may not be the same as those needed to perform tasks that separately involve the recall of colours or locations.

CHAPTER 4

STUDY 3

VISUAL SHORT-TERM MEMORY FOR SHAPES, COLOURS AND SHAPE- COLOUR BINDINGS IN CHILDREN AT RISK OF LEARNING DISABILITIES

4.1 Introduction

Since the seminal works by Atkinson and Shiffrin (1968) and by Baddeley and Hitch (1974), a great amount of knowledge has accumulated on the temporary retention of specific types of visual information such as colours, shapes, faces, abstract patterns, and spatial locations. More recently, efforts have been made towards understanding how complex, multi-feature visual information are temporarily held in memory. In particular, evidences suggest that memory capacity is constrained by the number of objects, and not by the number of composing features (Luck & Vogel, 1997). Furthermore, the processes by which features are integrated into memory seem to occur automatically, and bound objects are held without requiring more attentional resources than those needed to hold single features (Allen et al., 2012; Baddeley et al., 2011). It is still a controversial matter, however, whether a specialised visuospatial memory or a general memory component (such as the episodic buffer) is responsible for binding features and holding complex objects. In the present study, we assessed memory for single features (colours and shapes) and integrated features (shape-colour bindings), comparing two groups of children at risk of learning disabilities with a third group of typically developing children.

We adopted an individual differences, neuropsychological approach as a valid way to advance theoretical issues on memory (Cornoldi & Vecchi, 2003; Cornoldi & Mammarella, 2011). Specific deficits in working memory processes may shed light on the cognitive and neural substrates underpinning a given task. On the other hand, it may help understanding memory problems in children with learning difficulties.

A previous study by Jarrold et al. (2007) revealed that individuals with Williams syndrome and children with moderate learning disability have a deficit in memory for item-location binding, whereas memory for either items or locations is spared. From a theoretical point of view, these results suggest a dissociation between memory for features and bound objects. Given that the authors did not provide detailed information on the children's neuropsychological profile and learning difficulties, one cannot derive conclusions on the source of the memory binding deficit. In order to investigate this issue, for the present study we have selected a group of children with poor visuospatial skills.

4.2 Objectives and hypotheses

The present study examined to what extent different populations at risk of learning disabilities have a specific deficit in binding. We selected two groups of children with discrepant levels of cognitive skills. One group characterised by lower verbal and average spatial skills was considered at risk of verbal learning disabilities (VLD), given that low scores on verbal intelligence tasks are highly related to poor reading achievement (Richman & Lindgren, 1980). Another group characterised by average verbal and low spatial skills was considered at risk of nonverbal learning disabilities (NLD) (Mammarella & Pazzaglia, 2010; see also section 1.5). Finally, a third group of typically developing children (TD) with average verbal and spatial skills was selected as a control group.

We adapted the visual short-term memory test devised by Parra and collaborators to assess older adults populations (presented in Section 1.4; see also Della Sala et al., 2012; Parra, Abrahams, Logie, & Della Sala, 2010; Parra, Abrahams, Logie, Méndez, et al., 2010), and the procedure was slightly modified in order to increase task difficulty for children. In particular, in the trials in which the test display was different from the studied display, only one stimulus changed (out of two or out of three, depending on the testing phase).

As a working hypothesis, we expected that children with poor visuospatial skill would have a deficit in binding, mainly as a result of poor VSWM as observed in our Study 2. Thus, we expected that poor VSWM would be related to an impaired visual binding. On the other hand, children with poor verbal skills were not expected to have a deficit in visual binding, given that the test is simple and does not depend on verbal skills.

4.3 Method

Participants

Screening phase and group selection

This research followed the Ethical Principles of the Declaration of Helsinki and the Deontological Code of the Italian Order of Psychologists. The initial sample comprised 444 children (225 girls and 219 boys) aged 8 to 10 years (mean age = 107.1 months, $SD = 8.9$), attending 3rd or 4th grades of elementary school in small Italian towns. General verbal and visuospatial abilities were respectively assessed using the Verbal Meaning and Spatial

Relations subtests of the PMA (Thurstone & Thurstone, 1963, 1985). The mean score was 18.0 ($SD = 7.86$) for the verbal subtest, and 9.6 ($SD = 4.76$) for the spatial subtest.

Fifty-five children from the whole sample were selected to participate in the present study. In particular, children were identified at risk of learning disabilities on the basis of discrepancies observed between verbal and spatial scores. Eighteen children at risk of NLD (8 girls and 10 boys, mean age 9.0 years, $SD = .7$) scored below 1 SD in the spatial subtest and had average verbal scores. Seventeen children at risk of VLD (6 girls and 11 boys, mean age 8.6 years, $SD = .7$) scored around 1.5 SD below in the verbal subtest and had average spatial scores. Finally, twenty children (12 girls and 8 boys, mean age 8.9 years, $SD = .5$) with typical development (TD) were selected as a control group, and they had average scores in the above-mentioned tests. The groups did not differ according to age, $F(2, 52) = 2.61$, $p = .083$, or to gender distribution, $\chi^2(2) = 2.34$, $p = .31$.

During group selection, children were matched for sociocultural level and were evaluated for visual perception. We administered the simplified five-plates evaluation of the Ishihara's Test to assess colour deficiency and each participant received one point for each correct plate. We also administered a simplified shape-colour binding discrimination task as described in Parra et al. (2010). Two arrays of three coloured shapes each were simultaneously presented on the screen, one in the upper half and one in the lower half. In a series of 10 trials the participants had to judge if the two arrays were the 'same' or 'different'. In particular, the same three colours and three shapes appeared in both arrays, but the shape-colours combinations matched only in half of the trials (the 'same' response). In the other half, the shape-colour combinations varied between the arrays (the 'different' response). Participants received one point for each correct trial. The three groups had a similar performance in the Ishihara Test and shape-colour binding discrimination task. Table 4.1 summarizes the descriptive statistics for the children's performance by group (TD, VLD and NLD) and the results of group comparisons based on one-way ANOVA and the Bonferroni post hoc test.

Table 4.1

Characteristics of Participants Entering Study 3

Test	TD	VLD	NLD	One-way ANOVA	
	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>	<i>F(2, 52)</i>	Bonferroni post hoc ^a
PMA-spatial	10.5 (1.36)	10.4 (2.12)	4.0 (0.9)	109.45***	NLD < TD; NLD < VLD
PMA-verbal	20.6 (2.41)	5.7 (2.39)	19.6 (3.45)	158.39***	VLD < TD; VLD < NLD
Ishihara	4.20 (1.05)	4.05 (1.25)	3.83 (1.15)	< 1	ns
Binding discrimination	8.85 (1.39)	9.05 (1.03)	8.33 (1.28)	1.58	ns

Note. PMA, Ishihara and binding discrimination are raw scores. TD = typical development; VLD = verbal learning disability; NLD = nonverbal learning disability; ns = non-significant.

^a Only significant pairwise comparison are given.

*** $p < .001$.

Materials and procedure

A laptop computer with a 15-inch screen was used and all experimental procedures were programmed with the E-Prime software (W Schneider et al., 2002). The stimulus pool consisted of 72 coloured shapes each measuring approximately 1.5 cm² (cf. Parra, Abrahams, Logie, & Della Sala, 2010), generated by the combination of eight shapes (six-sided polygons) and nine colours (Figure 4.1; for further details see also Appendix D, p. 93).

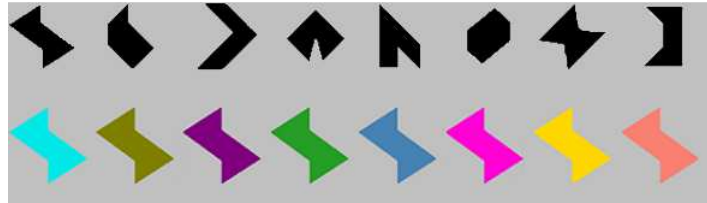


Figure 4.1. Shapes and colours used to construct stimuli arrays.

The tests were administered in a quiet room at the child's school during a single, individual session. The session started with the assessment of colour vision and shape-colour binding discrimination. After the initial visual perception assessment, visual short-term memory for single features (shapes and colours) and for shape-colour bindings was assessed in three blocked conditions counterbalanced according to a randomized Latin square. At the beginning of each block there were 10 training trials, followed by 40 experimental trials – 20 with 2-stimuli load and 20 with 3-stimuli load. A trial began with a fixation screen presented for 500 ms, followed by the study display for 2000 ms. After a retention interval of 900 ms, the test display was presented until response. On half of the trials, the stimuli on the study and test display were the same and on the other half the test was different (Figure 4.2). In the different trials of the shape and colour conditions, one stimulus remained the same in the study display, and one new stimulus (in trials with 2-stimuli load) or two new stimuli (in trials with 3-stimuli load) appeared on the test display. For the shape-colour binding condition, two studied stimuli appeared on the test display with swapped colours (for the complete list of trials see Appendix D, tables D.1, D.2, and D.3). Thus, only the memorization of the shapes and their respective colours (i.e., shape-colour bindings) would allow the detection of changes. Stimuli locations in both study and test displays were always randomly defined using a 3 x 3 virtual grid (see Figure D.1 on Appendix D), so that location was irrelevant to the task and could not be used as a memory cue. In the shape condition, only monochromatic black shapes were used and in the colour condition a random shape remained constant within a trial. For both colour and shape-colour binding conditions the black colour was not used due to its saliency.

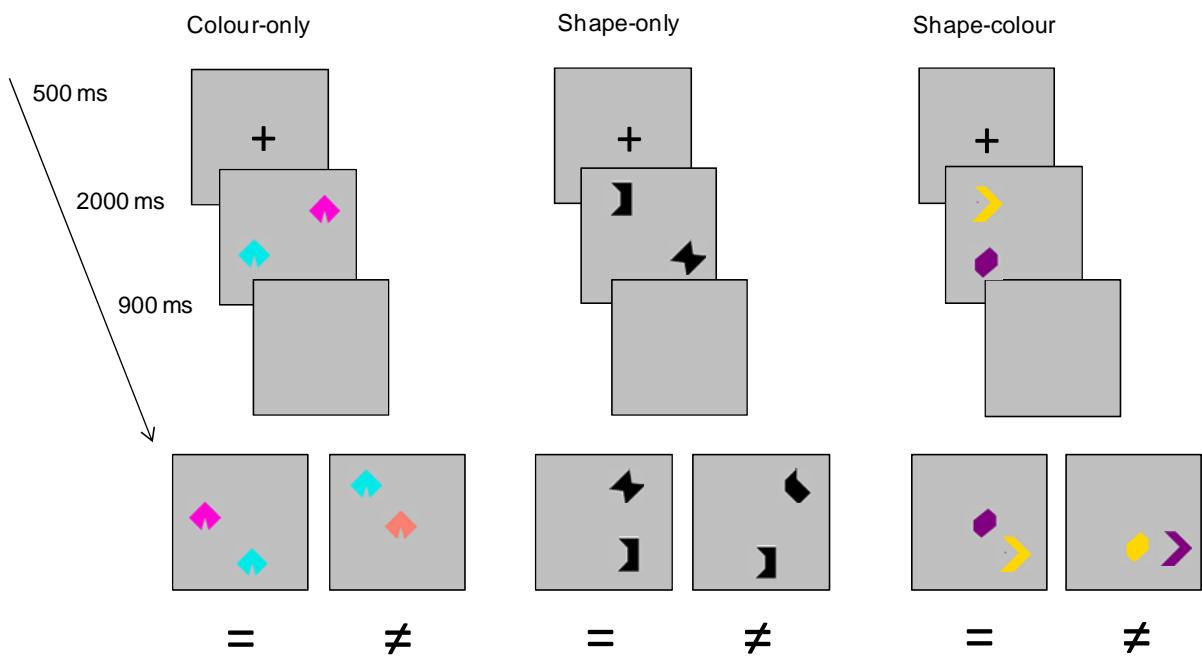


Figure 4.2. Schematic of the visual short-term memory test: different experimental conditions require recognition of shapes, colours, and shape-colour bindings.

4.4 Results

Data scoring

As a measure of performance we adopted sensitivity A' from the signal detection theory (Stanislaw & Todorov, 1999), the dependent variable recommended by Parra et al. (2010) to evaluate performance in this recognition task. This measure takes into consideration both hit and false-alarm rates and provides information on the degree of overlapping between the signal and the noise distributions, that is, the higher the sensitivity the better is the discrimination between the 'same' and 'different' conditions. There are two formulae for calculating A' according to the observed hit H and false-alarm F rates:

$$A' = .5 + \frac{(H - F)(1 + H - F)}{4H(1 - F)} \quad \text{when } H \geq F$$

$$A' = .5 + \frac{(F - H)(1 + F - H)}{4F(1 - H)} \quad \text{when } H < F$$

Data screening

Two participants belonging to the TD group did not fully understand the colour-shape match required by the binding task and were not included in the analysis. Other two participants (one belonging to the NLD and another to the TD group) were not included in the analysis due to a random, outlier performance in the shape condition. Therefore, we considered for statistical analysis the data from 51 participants (i.e., 17 per group).

Statistical analyses

Mean sensitivity for the change detection (A') is shown in Figure 4.3. We performed a two-way mixed ANOVA with group as the between-subjects factor (TD vs. VLD vs. NLD) and condition as the within-subjects factor (shape vs. colour vs. shape-colour binding). There was a main effect of group, $F(2, 48) = 4.4$, $MSE = .003$, $p = .018$, $\eta^2_p = .15$, a main effect of condition, $F(2, 96) = 54.9$, $MSE = .002$, $p < .001$, $\eta^2_p = .53$, and an interaction, $F(4, 96) = 2.7$, $MSE = .002$, $p = .035$, $\eta^2_p = .10$. The Tukey post hoc test on the group effect revealed that the NLD and VLD groups did not differ from each other, and both differed from the TD group around the significance criteria (respectively, $p = .024$ and $p = .056$). The post hoc test on the condition effect showed that performance differed across all conditions ($p < .01$ in all comparisons) (shapes: $M = .903$, $SE = .007$; colours: $M = .966$, $SE = .003$; binding: $M = .869$, $SE = .010$). Regarding the interaction effect, pairwise comparisons carried out across groups for each condition separately showed that a significant group difference emerged only in the binding condition. In particular, the TD group performed better than the NLD ($p = .002$; mean difference = $.069$, $SE = .023$), but did not differ from the VLD ($p = .076$; mean difference = $.051$, $SE = .023$).

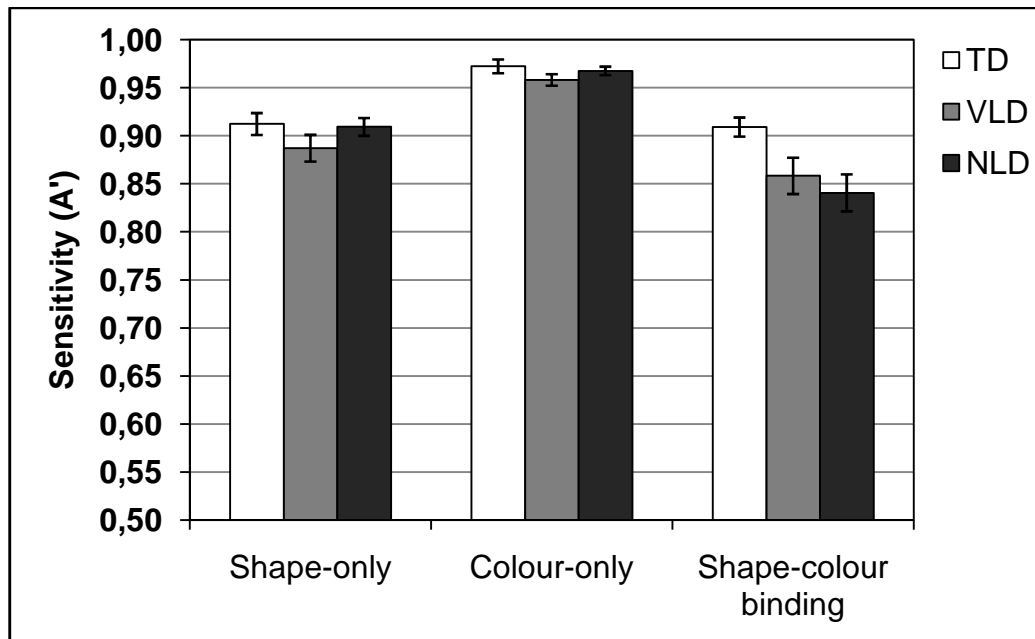


Figure 4.3. Mean sensitivity (A') in the three experimental conditions for the three groups of children. Error bars represent standard errors.

4.5 Discussion

This study focused on short-term retention of shapes, colour and shape-colour bindings in children at risk of learning disabilities (NLD and VLD) and in TD controls. Our aim was to ascertain whether children with poor verbal or visuospatial skills have a deficit in binding, or whether such deficit would be specific of children with poor visuospatial skills.

The results are straightforward: shape-colour binding is impaired in both groups at risk of learning disabilities, and there are strong reasons to support that this deficit is specific to binding processes in memory. Firstly, all groups of children succeed in the binding perception task, that is, they were able to discriminate shape-colour changes in visual arrays, ruling out the possibility that failures in memory resulted from perceptual problems. Secondly, all groups had a similar performance in memory for either colours or shapes, indicating that visual memory for features is spared.

Our results provide further support that problems in memory binding may be widespread across different populations with learning difficulties and atypical development (Jarrold et al., 2007). It should be noticed that Jarrold et al. (2007) investigated memory for items, locations and item-location bindings in individuals with Williams syndrome and children with moderate learning disability. In despite of differences between procedures

(colour-shape vs. item-location) and sample characteristics, both studies have produced comparable results and suggest generalised memory binding problems in atypical developing populations.

This is a very different scenario than the one observed in studies with older adults, in which a deficit in visual memory binding was found to be specific of individuals with Alzheimer's Disease (AD) (Della Sala et al., 2012; Parra, Abrahams, Logie, & Della Sala, 2010; Parra, Abrahams, Logie, Méndez, et al., 2010). In fact, memory binding in general seems to be impaired in AD regardless of type of information (verbal or visual) and retrieval process (recall and recognition) (Della Sala et al., 2012). According to Della Sala et al. (2012), this seems to be related to severe impairments in a large network involving the medial temporal lobe and fronto-parietal structures, all involved in relational representations.

Interestingly, evidences so far seem to indicate similar general binding deficits in children with atypical development, although only further studies would confirm this generalisation. It should be highlighted that patients with AD have a very low, chance-level performance in binding, indicating a severe impairment in neural mechanisms of binding. On the other hand, children with learning difficulties have a poorer performance in comparison with typically developing children, but they are far of presenting chance-level performance. This may suggest poor cognitive functioning and, in our view, children with learning difficulties seem to have problems in relating (or binding) different sorts of information, a process that is crucial to learning. Thus, it seems that difficulties in learning might be related to an impairment in binding related events and information. Our findings will need to be confirmed and extended, however, because one limitation of our study concerns the sample selection. Future research should include a wider range of developmental disorders and working memory tasks.

Concluding remarks

The present thesis addressed two broad questions about feature binding in visuospatial working memory: What is the nature of bound visual representations in working memory? Is there a specific deficit in binding in individuals with impaired VSWM?

In Study 1, young adults were required to recall locations, objects, and object-locations under visual and spatial interference conditions. A clear double dissociation between visual and spatial components of working memory was found: a spatial concurrent task majorly disrupted location-memory, whereas a visual concurrent task mainly disrupted object-memory. Furthermore, we found that bound object representations are prone to selective interference effects, providing support for an associative view of binding, that is, bound object representations in working memory seem to depend on information held in specific stores. When a concurrent task disrupts the updating of a specific feature, then part of an object representation is lost.

In Study 2, children with specific learning disabilities and typically developing children performed three tasks that required forward and backward recall of locations, colours, and colour-location bindings. Children with nonverbal learning disability had an impaired backward recall of locations (i.e., the backward version of the Corsi test), and an impaired recall of colours. Such deficiencies were not apparent in the colour-location binding task, but this task was too difficult to allow strong conclusions about binding processes.

Finally, in Study 3, children at risk of learning disabilities and typically developing children performed a visual short-term memory test for colours, shapes, and shape-colour bindings. Both groups at risk of learning disabilities had an impaired memory for shape-colour bindings, whereas no group differences in memory were observed for either shapes or colours. This indicates that a visual binding deficit is not related to poor visuospatial skills or working memory, but it seems to derive from an impairment in forming links between related events and information.

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Appendices

A. Parecer do Comitê de Ética em Pesquisa da FFCLRP-USP

UNIVERSIDADE DE SÃO PAULO
FACULDADE DE FILOSOFIA, CIÊNCIAS E LETRAS DE RIBEIRÃO PRETO
COMITÊ DE ÉTICA EM PESQUISA - CEP

Of.CEtP/FFCLRP-USP.007/2010-25/3/2010

Senhor(a) Pesquisador(a):

Comunicamos a V. Sa. que o trabalho intitulado "**A Memória não-verbal a curto prazo: Componentes Funcionais e Manutenção da Ordem Serial**", foi analisado pelo Comitê de Ética em Pesquisa da FFCLRP-USP, e, enquadrado na categoria: **APROVADO**, de acordo com o Processo CEP-FFCLRP nº 467/2009 – 2009.1.1956.59.0

Atenciosamente,


Profa. Dra. ANA RAQUEL LUCATO CIANFLONE
 Coordenadora do Comitê de Ética em Pesquisa – FFCLRP-USP

Ilustríssimo(a) Senhor(a):
Ricardo Basso Garcia
 Aluna do Programa de PG em Psicobiologia

c.c.:
 Prof. Dr. César Aléxis Galera
 Docente do Departamento de Psicologia e Educação
 Desta FFCLRP-USP

B. Materials used in Study 1

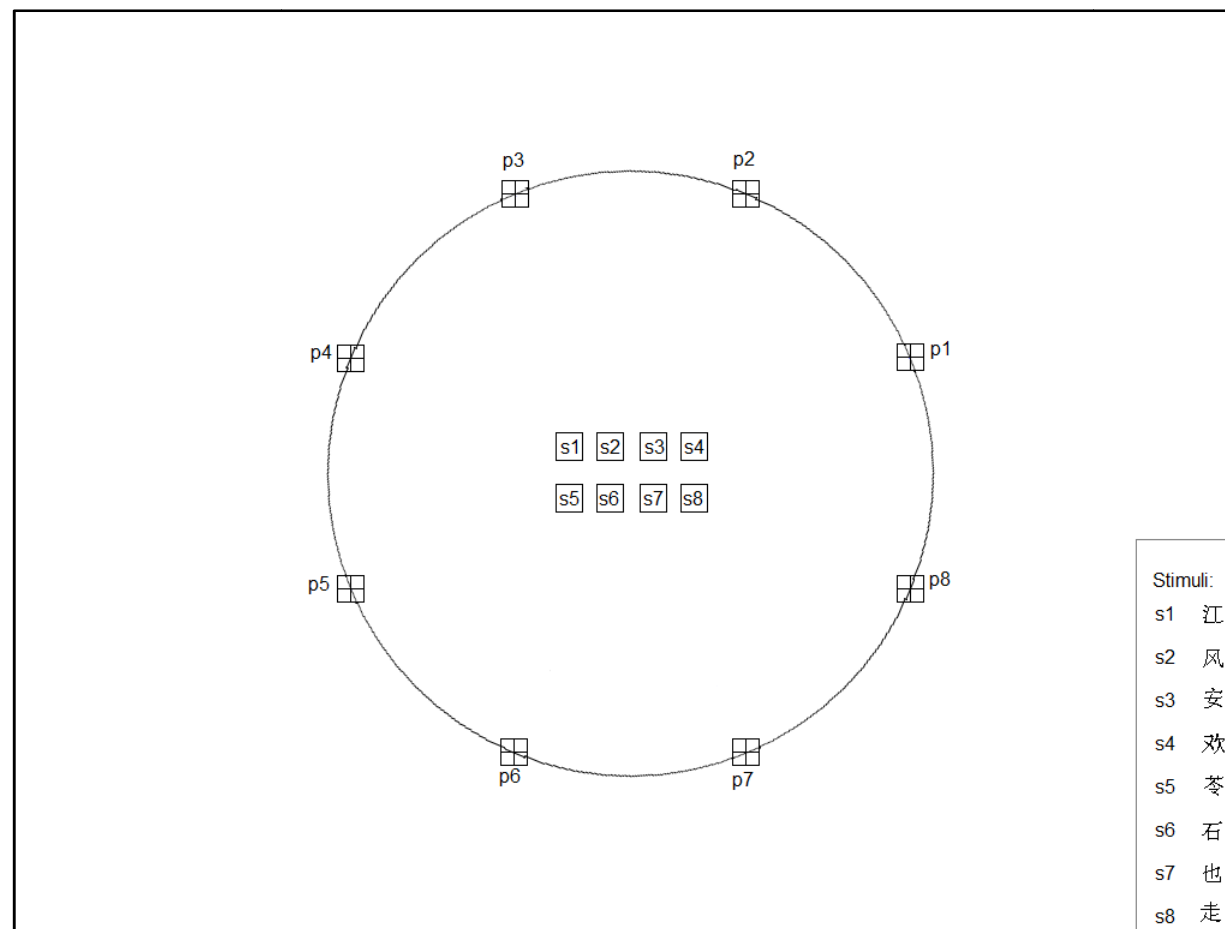


Figure B.1. Schematic of the task display used for response registration in Study 1. The background colour was black, the locations p1 to p8 were white squares and the stimuli s1 to s8 were displayed in black colour inside white squares.

B. Materials used in Study 1 (cont.)

Sixty-four stimuli were used in Study 1, given the combination between 8 stimuli (s1 to s8) and 8 locations (p1 to p8) (cf. Figure B.1). The stimuli were represented in the format 's x p y ', that is, ideograph sx appearing in location py :

s1p1	s5p1
s1p2	s5p2
s1p3	s5p3
s1p4	s5p4
s1p5	s5p5
s1p6	s5p6
s1p7	s5p7
s1p8	s5p8
s2p1	s6p1
s2p2	s6p2
s2p3	s6p3
s2p4	s6p4
s2p5	s6p5
s2p6	s6p6
s2p7	s6p7
s2p8	s6p8
s3p1	s7p1
s3p2	s7p2
s3p3	s7p3
s3p4	s7p4
s3p5	s7p5
s3p6	s7p6
s3p7	s7p7
s3p8	s7p8
s4p1	s8p1
s4p2	s8p2
s4p3	s8p3
s4p4	s8p4
s4p5	s8p5
s4p6	s8p6
s4p7	s8p7
s4p8	s8p8

C. Materials used in Study 2

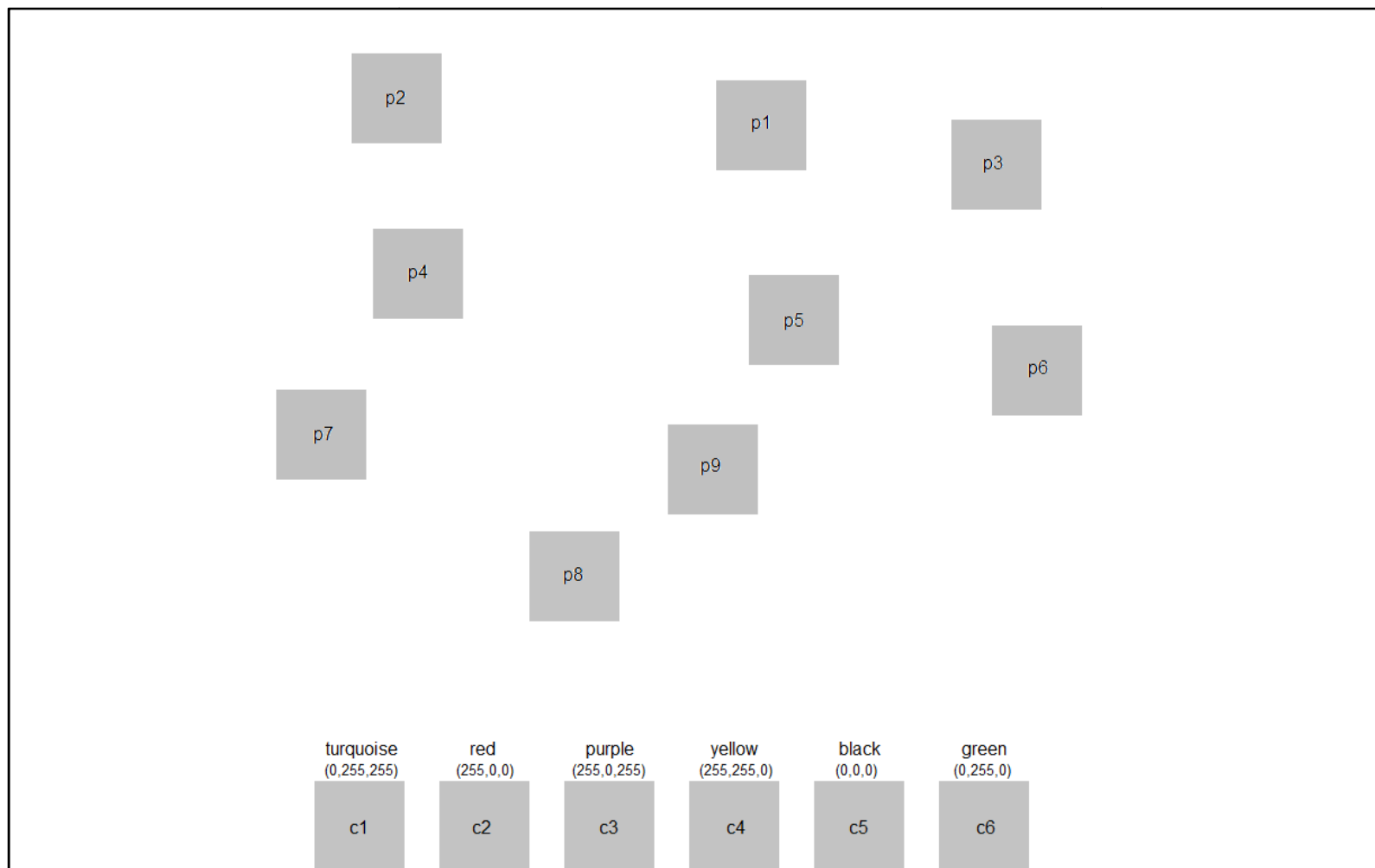


Figure C. 1. Schematic of the task display used for response registration in Study 2. The labels p1 to p9, c1 to c6, and colour names/codes were not visible to the participant.

C. Materials used in Study 2 (cont.)

The scheme for presenting the stimuli was similar for all the tests (i.e., Corsi, Colour, and Binding) conducted in the Study 2: A trial consisted of a sequence of coloured squares. There were 9 locations (p1 to p9) and 6 colours (c1 to c6) (cf. Figure C.1). Tables C.1 and C.2 list all the location-colour sequences 'pxcy' (i.e., colour cy appeared in location px) used in Study 2.

Table C.1

Stimuli used in each trial of the forward version of the Corsi, Colour, and Binding tests

Task	Sequence length	Serial positions and stimuli					
		1	2	3	4	5	6
Corsi	2	p2c6	p7c5				
	2	p1c1	p8c4				
	3	p3c6	p8c4	p9c3			
	3	p1c4	p4c5	p6c3			
	4	p6c4	p1c5	p2c6	p7c1		
	4	p2c1	p9c5	p7c2	p3c4		
	5	p6c4	p3c2	p7c1	p8c6	p5c3	
	5	p3c6	p9c5	p6c2	p4c3	p7c4	
	6	p4c6	p5c5	p9c2	p7c1	p2c3	p1c4
	6	p9c2	p6c5	p4c3	p7c4	p8c1	p2c6
Colour	2	p4c2	p6c3				
	2	p5c1	p1c6				
	3	p1c2	p6c3	p8c1			
	3	p8c4	p2c5	p7c3			
	4	p4c1	p5c4	p8c2	p9c6		
	4	p8c6	p1c2	p4c4	p2c5		
	5	p4c4	p8c2	p2c5	p5c1	p1c6	
	5	p9c3	p2c6	p3c4	p6c5	p7c1	
Binding	2	p8c5	p3c3				
	2	p7c3	p2c1				
	3	p4c4	p6c1	p2c5			
	3	p8c2	p5c6	p1c3			
	4	p5c1	p1c4	p4c6	p7c2		
	4	p1c5	p9c4	p3c1	p4c2		
	5	p8c1	p1c2	p3c4	p2c6	p7c5	
	5	p9c2	p1c6	p8c4	p3c5	p5c3	

C. Materials used in Study 2 (cont.)

Table C.2.

Stimuli used in each trial of the backward version of the Corsi, Colour, and Binding tests

Task	Sequence length	Serial positions and stimuli					
		1	2	3	4	5	6
Corsi	2	p8c1	p5c6				
	2	p4c3	p3c4				
	3	p8c1	p4c6	p1c4			
	3	p2c6	p9c5	p3c3			
	4	p7c1	p5c6	p3c5	p2c4		
	4	p1c3	p9c2	p4c1	p6c4		
	5	p5c1	p4c4	p8c5	p1c6	p6c2	
	5	p7c3	p1c1	p2c5	p4c2	p9c6	
	6	p3c1	p6c6	p9c2	p4c3	p5c4	p2c5
	6	p8c3	p9c4	p2c5	p4c1	p7c6	p3c2
Colour	2	p4c5	p6c4				
	2	p5c4	p1c6				
	3	p9c1	p1c2	p7c6			
	3	p1c3	p6c2	p8c5			
	4	p4c5	p5c4	p8c6	p9c3		
	4	p8c3	p1c1	p4c5	p2c2		
	5	p4c1	p8c4	p2c5	p5c6	p1c2	
	5	p9c3	p2c2	p3c1	p6c5	p7c4	
Binding	2	p5c3	p3c2				
	2	p8c6	p1c5				
	3	p1c6	p4c1	p5c2			
	3	p9c4	p1c2	p6c3			
	4	p8c3	p5c5	p3c6	p6c1		
	4	p3c4	p4c3	p6c5	p7c2		
	5	p9c5	p3c1	p1c3	p4c2	p5c6	
	5	p8c2	p1c4	p2c1	p9c6	p3c3	

D. Materials used in Study 3

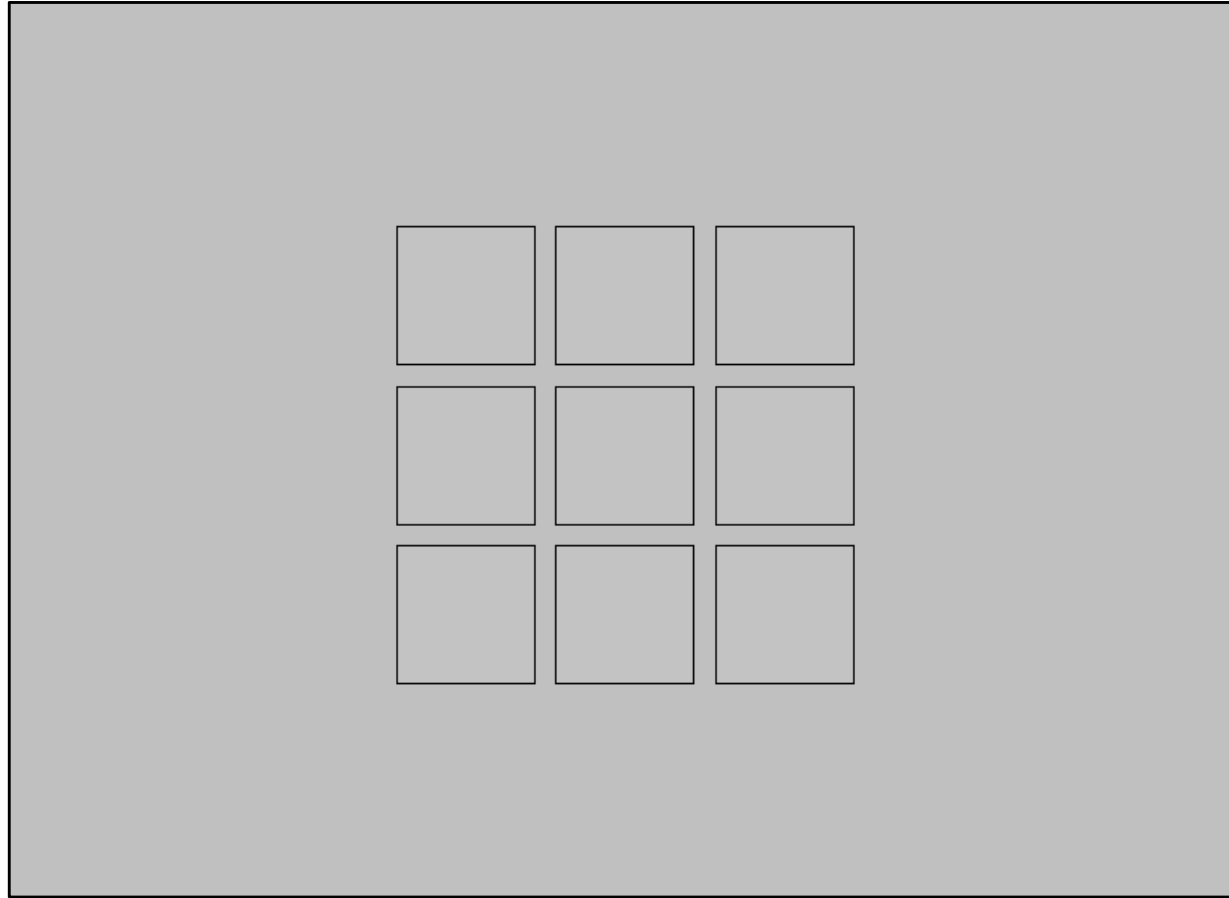


Figure D.1. Schematic of the task display used for stimuli presentation in Study 3. Stimuli appeared on random locations and the squares were not visible to the participant.

D. Materials used in Study 3 (cont.)

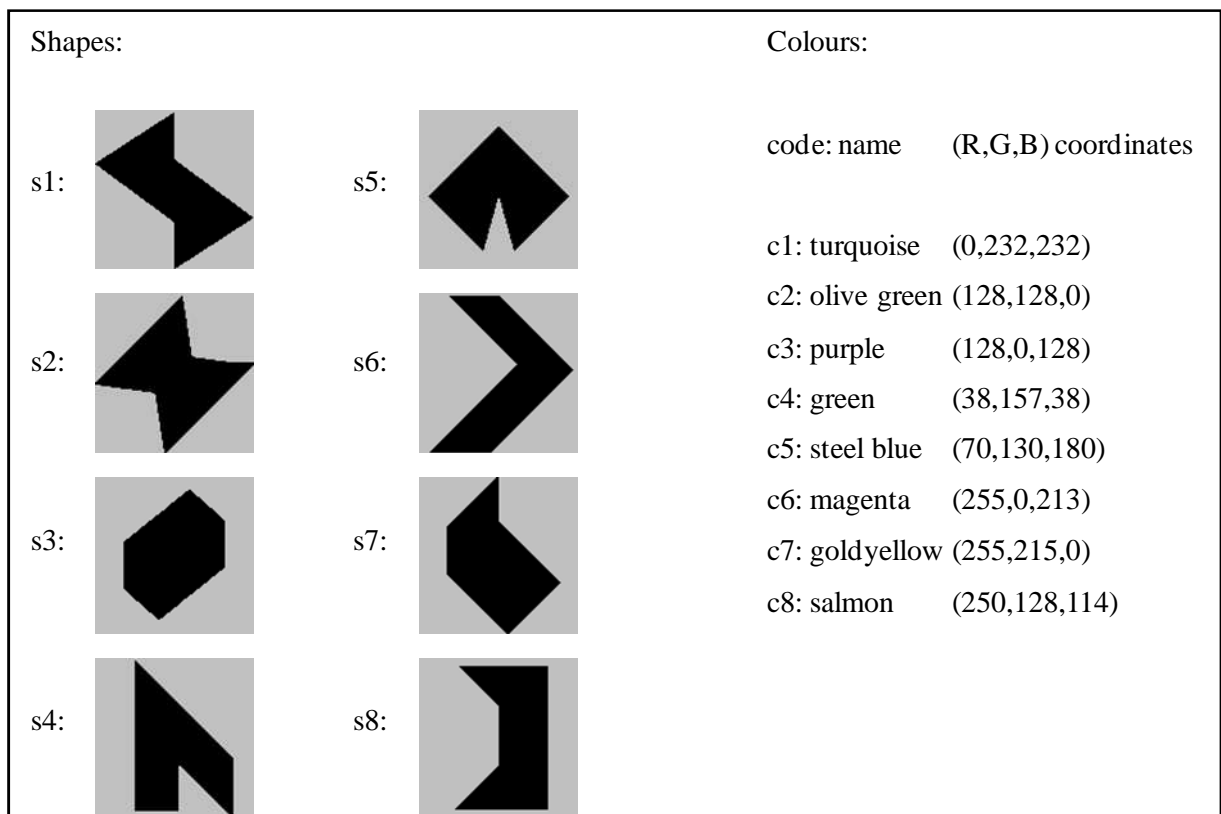


Figure D.2. The shapes (s1 to s8) and colours (c1-c8) used in Study 3.

Sixty-four stimuli were used in Study 3, given the combination between 8 shapes (s1 to s8) and 8 colours (c1 to c8) (cf. Figure D.2):

s1c1	s5c1	s3c1	s7c1
s1c2	s5c2	s3c2	s7c2
s1c3	s5c3	s3c3	s7c3
s1c4	s5c4	s3c4	s7c4
s1c5	s5c5	s3c5	s7c5
s1c6	s5c6	s3c6	s7c6
s1c7	s5c7	s3c7	s7c7
s1c8	s5c8	s3c8	s7c8
s2c1	s6c1	s4c1	s8c1
s2c2	s6c2	s4c2	s8c2
s2c3	s6c3	s4c3	s8c3
s2c4	s6c4	s4c4	s8c4
s2c5	s6c5	s4c5	s8c5
s2c6	s6c6	s4c6	s8c6
s2c7	s6c7	s4c7	s8c7
s2c8	s6c8	s4c8	s8c8

D. Materials used in Study 3 (cont.)

Table D.1

List of stimuli (shapes: s1 to s8) presented in study and test displays

Trial type	Stimuli in study display			Stimuli in test display ^a		
	1	2	3	1	2	3
same	s1	s4		s1	s4	
same	s3	s6		s3	s6	
same	s5	s8		s5	s8	
same	s4	s5		s4	s5	
same	s2	s4		s2	s4	
same	s1	s2		s1	s2	
same	s6	s7		s6	s7	
same	s2	s6		s2	s6	
same	s1	s6		s1	s6	
same	s2	s8		s2	s8	
different	s3	s2		s3	s1	
different	s4	s7		s4	s1	
different	s8	s6		s8	s4	
different	s5	s1		s5	s2	
different	s3	s4		s3	s6	
different	s3	s1		s3	s5	
different	s1	s8		s1	s3	
different	s8	s7		s8	s4	
different	s7	s5		s7	s8	
different	s2	s5		s2	s7	
same	s6	s3	s7	s6	s3	s7
same	s4	s5	s2	s4	s5	s2
same	s1	s8	s7	s1	s8	s7
same	s2	s5	s3	s2	s5	s3
same	s4	s6	s1	s4	s6	s1
same	s8	s7	s4	s8	s7	s4
same	s6	s3	s8	s6	s3	s8
same	s5	s2	s1	s5	s2	s1
same	s3	s5	s8	s3	s5	s8
same	s2	s4	s7	s2	s4	s7
different	s6	s1	s5	s6	s7	s2
different	s3	s5	s7	s3	s4	s1
different	s6	s8	s1	s6	s2	s7
different	s5	s6	s7	s5	s4	s1
different	s2	s1	s3	s2	s5	s8
different	s8	s4	s5	s8	s6	s3
different	s1	s2	s6	s1	s7	s3
different	s1	s7	s3	s1	s8	s5
different	s3	s8	s4	s3	s5	s6
different	s5	s6	s2	s5	s8	s1

^a New stimuli presented on the test display are in bold.

D. Materials used in Study 3 (cont.)

Table D.2

List of stimuli (colours, c1 to c8) presented in study and test displays

Trial type	Stimuli in study display			Stimuli in test display ^a		
	1	2	3	1	2	3
same	s6c2	s6c5		s6c2	s6c5	
same	s4c4	s4c7		s4c4	s4c7	
same	s6c6	s6c8		s6c6	s6c8	
same	s7c3	s7c4		s7c3	s7c4	
same	s4c4	s4c8		s4c4	s4c8	
same	s5c1	s5c3		s5c1	s5c3	
same	s3c2	s3c6		s3c2	s3c6	
same	s8c1	s8c6		s8c1	s8c6	
same	s2c5	s2c7		s2c5	s2c7	
same	s1c2	s1c8		s1c2	s1c8	
different	s4c3	s4c2		s4c3	s4c4	
different	s2c5	s2c3		s2c5	s2c6	
different	s1c8	s1c1		s1c8	s1c5	
different	s3c5	s3c4		s3c5	s3c2	
different	s8c4	s8c6		s8c4	s8c3	
different	s7c5	s7c6		s7c5	s7c8	
different	s5c1	s5c4		s5c1	s5c7	
different	s6c2	s6c7		s6c2	s6c8	
different	s8c8	s8c3		s8c8	s8c1	
different	s1c3	s1c6		s1c3	s1c7	
same	s5c7	s5c2	s5c3	s5c7	s5c2	s5c3
same	s1c8	s1c4	s1c5	s1c8	s1c4	s1c5
same	s2c8	s2c5	s2c7	s2c8	s2c5	s2c7
same	s4c6	s4c1	s4c4	s4c6	s4c1	s4c4
same	s8c2	s8c5	s8c6	s8c2	s8c5	s8c6
same	s3c8	s3c2	s3c4	s3c8	s3c2	s3c4
same	s6c1	s6c3	s6c8	s6c1	s6c3	s6c8
same	s7c2	s7c4	s7c1	s7c2	s7c4	s7c1
same	s1c3	s1c6	s1c2	s1c3	s1c6	s1c2
same	s5c7	s5c5	s5c1	s5c7	s5c5	s5c1
different	s3c6	s3c2	s3c7	s3c6	s3c4	s3c1
different	s8c8	s8c4	s8c1	s8c8	s8c7	s8c5
different	s6c8	s6c5	s6c3	s6c8	s6c4	s6c6
different	s2c5	s2c4	s2c1	s2c5	s2c2	s2c3
different	s4c4	s4c6	s4c7	s4c4	s4c3	s4c8
different	s7c3	s7c4	s7c5	s7c3	s7c8	s7c6
different	s6c2	s6c4	s6c7	s6c2	s6c5	s6c3
different	s8c7	s8c8	s8c4	s8c7	s8c1	s8c6
different	s5c6	s5c5	s5c7	s5c6	s5c3	s5c2
different	s7c8	s7c3	s7c6	s7c8	s7c5	s7c7

^a New stimuli presented on the test display are in bold. In each trial, the shape 'sx' remained constant.

D. Materials used in Study 3 (cont.)

Table D.3

List of stimuli (shape-colours, fxcy) presented in study and test displays

Trial type	Stimuli in study display			Stimuli in test display ^a		
	1	2	3	1	2	3
same	s2c1	s4c7		s2c1	s4c7	
same	s1c6	s8c8		s1c6	s8c8	
same	s3c4	s6c3		s3c4	s6c3	
same	s6c5	s5c2		s6c5	s5c2	
same	s6c7	s3c8		s6c7	s3c8	
same	s4c5	s7c2		s4c5	s7c2	
same	s8c4	s3c7		s8c4	s3c7	
same	s7c1	s2c4		s7c1	s2c4	
same	s1c7	s5c6		s1c7	s5c6	
same	s5c3	s2c8		s5c3	s2c8	
different	s7c7	s3c5		s7c5	s3c7	
different	s3c6	s5c4		s3c4	s5c6	
different	s7c3	s6c8		s7c8	s6c3	
different	s1c2	s3c1		s1c1	s3c2	
different	s8c7	s7c8		s8c8	s7c7	
different	s3c2	s5c5		s3c5	s5c2	
different	s2c5	s5c7		s2c7	s5c5	
different	s6c6	s4c1		s6c1	s4c6	
different	s8c3	s6c4		s8c4	s6c3	
different	s1c8	s8c6		s1c6	s8c8	
same	s8c3	s4c5	s5c1	s8c3	s4c5	s5c1
same	s1c8	s6c2	s8c4	s1c8	s6c2	s8c4
same	s2c3	s6c1	s4c8	s2c3	s6c1	s4c8
same	s5c4	s7c3	s2c1	s5c4	s7c3	s2c1
same	s7c7	s8c6	s3c2	s7c7	s8c6	s3c2
same	s6c5	s2c7	s8c8	s6c5	s2c7	s8c8
same	s5c5	s3c6	s8c2	s5c5	s3c6	s8c2
same	s2c2	s1c6	s4c1	s2c2	s1c6	s4c1
same	s4c4	s8c7	s2c8	s4c4	s8c7	s2c8
same	s4c3	s2c5	s3c8	s4c3	s2c5	s3c8
different	s7c4	s8c1	s3c3	s7c4	s8c3	s3c1
different	s5c3	s7c5	s4c6	s5c3	s7c6	s4c5
different	s3c1	s5c7	s7c6	s3c1	s5c6	s7c7
different	s7c4	s2c8	s8c7	s7c4	s2c7	s8c8
different	s6c3	s1c4	s2c6	s6c3	s1c6	s2c4
different	s3c7	s7c1	s4c6	s3c7	s7c6	s4c1
different	s5c8	s6c2	s4c3	s5c8	s6c3	s4c2
different	s5c6	s1c1	s4c2	s5c6	s1c2	s4c1
different	s7c8	s1c2	s4c7	s7c8	s1c7	s4c2
different	s3c4	s6c6	s1c5	s3c4	s6c5	s1c6

^a New stimuli presented on the test display are in bold.

E. List of publications during the doctorate

Corder, A. P. U.; **Garcia, R. B.**; Vasques, R.; & Galera, C. (2012). A integração incidental da informação visual e espacial na memória de trabalho. *Psicologia Teoria e Prática*, 14(1), 113-25.

Garcia, R. B. (2012). The mind inside our skull. *Science*, 337(6092), 293-4.

Galera, C.; **Garcia, R. B.**; & Vasques, R. (2013). Componentes funcionais da memória visuoespacial. *Estudos Avançados*, 27(77), 29-43.