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REMISE EN QUESTION DE LA MODULARITÉ EN MÉMOIRE

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RÉSUMÉ

Le maintien de l'ordre en mémoire à court terme suscite depuis longtemps un intérêt marqué en psychologie cognitive expérimentale. Même si l'information à traiter dans l'environnement est souvent de nature spatiale, la plupart des recherches sur la mémoire à court terme portent sur le traitement de l'information verbale. Par ailleurs, le traitement de l'information verbale et spatiale en mémoire à court terme fait encore l'objet d'un débat en psychologie cognitive. Certains auteurs suggèrent qu'il existe un module indépendant responsable de traiter chaque type d'information (p. ex., Baddeley & Hitch, 1974). Cette approche est notamment supportée par la démonstration de dissociations entre le traitement de l'information verbale et le traitement de l'information spatiale (p. ex., Meiser & Klauer, 1999). Une approche unitaire quant à elle, soutient que les processus en mémoire sont indépendants du type d'information à traiter (p. ex., Jones, Macken, & Nicholls, 2004). Cette approche trouve appui parmi les études qui démontrent que la rétention de l'information spatiale et la rétention de l'information verbale produisent des patrons de performance équivalents (p. ex., Ward, Avons, & Melling, 2005). L'objectif de la thèse est de tester ces visions alternatives et de vérifier si les mêmes processus sont sollicités lors de la rétention de l'information verbale et spatiale. La rétention de l'information spatiale et verbale est comparée directement à l'aide d'une tâche classique de rappel où les participants doivent rappeler l'ordre dans lequel des séries d'items ont été présentées (Chapitre II). Une procédure de double dissociation combinée à une analyse approfondie des erreurs sont utilisées. Bien que les résultats démontrent la présence d'une double dissociation, le traitement de l'information verbale et spatiale produit des patrons d'erreurs équivalents. Dans le chapitre III, les facteurs qui influencent le rappel de l'information spatiale sont examinés afin de mieux comprendre la nature des processus responsables de retenir ce type d'information. Une analyse du mouvement oculaire combinée à l'utilisation d'une tâche de suppression oculaire montre que l'efficacité avec laquelle les yeux sont déplacés entre les items influence la mémoire pour les localisations spatiales. L'ensemble de ces résultats est interprété à la lumière d'une nouvelle approche théorique selon laquelle la coopération entre les systèmes perceptifs et moteurs sont responsables de la rétention de l'information.

ABSTRACT

The capacity to remember the order of events in the short term has been a key topic of study within experimental psychology. Although the retention of verbal information has received considerable attention in the literature, less is known about the retention of spatial material. Moreover, whether spatial and verbal materials are processed by common or separate mechanisms is still a matter of debate. Some authors suggest the existence of separate components for the processing of verbal and spatial information (e.g., Baddeley & Hitch, 1974). This view is supported by the demonstration of dissociations between the verbal and spatial domains (e.g., Meiser & Klauer, 1999). There is also evidence of functional equivalence such as the extension of classical verbal memory phenomena to the spatial domain (e.g., Ward, Avons, & Melling, 2005), which suggests that the processes that are called upon in a memory task are common to all types of information (unitary view; see e.g., Jones, Macken, & Nicholls, 2004). The objective of the present thesis is to test these two alternative views and to verify whether the same processes could be responsible for retaining verbal and spatial information. The retention of spatial and verbal information is compared directly using a classical serial recall task where participants are required to recall the order in which series of items were presented (Chapter II). A double dissociation procedure is used combined with an in-depth analysis of errors. The results indicate that even though a dissociation is observed, the patterns of errors are very similar between the verbal and spatial tasks. In Chapter III, the factors that modulate the recall of spatial information are examined in order to further our understanding of the processes responsible for the retention of spatial information. An analysis of eye movements combined with the use of ocular suppression show that the efficacy with which the eyes are moved between the different locations modulate recall performance for spatial information. These findings are interpreted in light of a new approach according to which the cooperation between the perceptual and gestural systems give rise to a variety of memory phenomena.

AVANT-PROPOS

La présente thèse a été rédigée sous forme d'articles. Le chapitre II a été publié dans la revue *Journal of Experimental Psychology : Learning Memory and Cognition*. Le chapitre III est actuellement sous presse dans la revue *Acta Psychologica*. Pour ces articles empiriques, j'ai fait la recension des écrits, développé le devis expérimental, recueilli et analysé les données et rédigé les articles. Ils ont été rédigés en collaboration avec mon directeur de thèse, le Dr. Sébastien Tremblay, qui est professeur-chercheur à l'École de psychologie de l'Université Laval. L'article du chapitre III a aussi été rédigé en collaboration avec le Dr. Jean Saint-Aubin qui est professeur-chercheur à l'École de psychologie de l'Université de Moncton au Nouveau-Brunswick.

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INTRODUCTION GÉNÉRALE

INTRODUCTION

L'individu fait constamment appel à un ensemble de processus mentaux afin de traiter les stimulations présentes dans l'environnement. Selon l'approche du traitement de l'information de la cognition humaine, ces processus sont organisés en une succession d'étapes qui permettent à l'individu d'acquérir l'information qui lui parvient par les sens afin de la transformer, de l'emmagasiner et éventuellement, de l'utiliser (voir Broadbent, 1958; Neisser, 1967). La présente thèse s'intéresse principalement à définir les processus responsables du traitement de l'information en mémoire à court terme (MCT). La MCT désigne un ensemble de mécanismes responsables d'encoder, de retenir, de manipuler et de récupérer l'information sur une courte période de temps (i.e. quelques secondes). La définition de ces mécanismes est fondamentale à la compréhension du fonctionnement de l'individu dans l'exécution de ses activités cognitives courantes.

Une fonction particulière de la MCT est de retenir l'ordre dans lequel les évènements sont présentés (voir p. ex., Ebbinghaus, 1885/ 1964; Lashley, 1951; Murdock, 1976). En effet, l'information dans l'environnement est souvent présentée de façon séquentielle. L'ordre des évènements n'est généralement pas aléatoire et il importe souvent qu'ils soient traités dans l'ordre où ils sont présentés. Le traitement de l'ordre est sollicité dans plusieurs activités quotidiennes, comme la conduite automobile, où l'ordre des actions à entreprendre est fondamental au bon déroulement de l'activité (p. ex., mettre le clignotant avant d'effectuer un changement de voie). La lecture est un autre exemple d'activité où l'ordre des mots est essentiel à la compréhension du sens d'une phrase. Afin d'étudier le traitement de l'ordre en laboratoire, une tâche classique est le rappel sériel. Au cours de cette tâche, des séquences d'items sont présentées aux participants. Après la présentation de chaque séquence, ceux-ci doivent rappeler les items dans l'ordre exact où ils ont été présentés (voir p. ex., Conrad, 1964).

La plupart des recherches portant sur la MCT, et plus particulièrement sur la mémoire de l'ordre, se sont intéressées au traitement de l'information dite verbale, c'est-à-dire liée au langage (p. ex., des lettres, des syllabes ou des mots). Le traitement de ce type d'information est un sujet privilégié dans le domaine de la MCT vu son importance dans la vie quotidienne et la facilité avec laquelle il est possible de manipuler un contenu verbal. En effet, des stimuli verbaux peuvent facilement être présentés dans deux modalités différentes (i.e., visuellement, oralement), sous plusieurs formes (p. ex., des mots, des lettres, des phrases), et lorsqu'ils sont visuels, de plusieurs façons (p. ex., séquentiellement, simultanément). Peu importe comment l'information verbale est présentée, l'articulation ou la prononciation des items semble jouer un rôle central dans la rétention (voir p. ex., Gathercole & Baddeley, 1993).

Bien que l'information verbale soit omniprésente dans la vie quotidienne de l'individu, l'information dans l'environnement n'est pas limitée au verbal. Par exemple, l'individu doit quotidiennement traiter la localisation où l'information est présentée. L'information spatiale doit être traitée dans une panoplie d'activités comme la lecture, où l'ordre des mots sur une page est déterminé par leur position spatiale relative. Cependant, malgré son importance dans la vie quotidienne, le traitement de l'information spatiale a été beaucoup moins étudié que le traitement de l'information verbale. Par conséquent, peu de modèles permettent d'expliquer comment l'individu retient l'information spatiale dans le temps (Parmentier, Andrés, Elford, & Jones, 2006; Smyth & Scholey, 1994). Dans un contexte de laboratoire, la rétention de l'information spatiale dans le temps est généralement étudiée à l'aide de marqueurs de localisations comme des points noirs (voir p. ex., Jones, Farrand, Stuart, & Morris, 1995) ou des cubes (voir p. ex., Smyth, 1996) présentés séquentiellement à différents endroits sur un écran d'ordinateur (voir Figure 1). Suite à la présentation de la séquence, l'ensemble des marqueurs est représenté simultanément et les participants doivent reconstruire l'ordre dans lequel ils avaient été présentés. Certains chercheurs soutiennent que le mouvement oculaire joue un rôle important afin de retenir les localisations en mémoire dans ce type de tâche (voir p. ex., Baddeley, 1986; Tremblay, Saint-Aubin, & Jalbert, 2006).

La rétention de l'information verbale et spatiale en mémoire fait l'objet d'un débat dans le domaine de la psychologie cognitive. Certains auteurs suggèrent que la MCT est subdivisée en composantes spécifiques au type d'information à retenir (p. ex., Baddeley, 1986; Baddeley & Hitch, 1974; Logie, 1995). Par exemple, la rétention d'une série de mots serait effectuée par un module indépendant, différent de celui responsable de retenir une série de localisations spatiales. Cette approche est notamment supportée par la démonstration de doubles dissociations entre le traitement de l'information verbale et celui de l'information spatiale. En neuroimagerie, une double dissociation est observée lorsque deux activités de natures différentes (p. ex., l'une verbale et l'autre spatiale) activent des régions cervicales distinctes (p. ex., Smith, Jonides, & Koeppe, 1996). Dans les études comportementales, une double dissociation survient lorsqu'une activité de nature verbale affecte sélectivement la rétention de l'information verbale, alors qu'une activité spatiale altère sélectivement la performance à une tâche de mémoire spatiale (p. ex., Farmer, Berman, & Fletcher, 1986; Meiser & Klauer, 1999).

Une autre approche, l'approche unitaire, ne fait pas appel à des modules spécialisés, mais soutient que les processus qui permettent de retenir l'information sont indépendants de la nature de l'information à traiter : lors d'une tâche de mémoire, les mêmes processus seraient sollicités, peu importe que les items soient des mots ou des localisations (p. ex., Cowan, 1993; Crowder, 1982; Jones, 1993; Jones, Hughes, & Macken, 2006). L'approche unitaire est supportée par les études qui démontrent que la rétention de l'information spatiale et la rétention de l'information verbale produisent des patrons de performance équivalents (p. ex., Jones et al., 1995; Smyth & Scholey, 1996; Ward, Avons, & Melling, 2005). La démonstration de phénomènes similaires entre le domaine verbal et le domaine spatial suggère que le recours à des modules spécifiques est superflu afin d'expliquer la performance à des tâches de mémoire. Alors que les similitudes entre le traitement de l'information verbale et le traitement de l'information spatiale suggèrent que les processus sollicités sont communs à tous les types de stimuli, les dissociations appuient une vision opposée selon laquelle des modules spécifiques entrent en jeu lors du traitement de l'information. Il n'existe donc pas de consensus relativement à l'unité de la MCT. L'objectif général de la thèse est d'examiner si les mêmes processus sont sollicités lors de la rétention de l'information verbale et spatiale.

DEUX VISIONS ALTERNATIVES DE LA MÉMOIRE

L'approche modulaire est l'approche prédominante dans le domaine de la MCT depuis les 50 dernières années (p. ex., Baddeley, 1986; Baddeley & Hitch, 1974; Logie, 1995). Cependant, certains chercheurs ont récemment questionné l'existence de modules spécifiques, ce qui a donné naissance à un nouveau courant de recherche visant à démontrer l'équivalence entre le traitement de l'information verbale et le traitement de l'information spatiale (p. ex., Jones et al., 1995).

L'APPROCHE MODULAIRE

Une vision modulaire suggère que la MCT est fragmentée en modules spécifiques au type d'information à traiter (p. ex., Baddeley, 1986; Baddeley & Hitch, 1974; voir aussi Wickens, 1984). Le modèle de la mémoire de travail (Baddeley, 1986, 2000; Baddeley & Hitch, 1974; Logie, 1995) est un exemple de modèle modulaire. Selon Baddeley et Hitch, la mémoire est subdivisée en plusieurs composantes spécialisées, dont la boucle phonologique, responsable du traitement de l'information verbale, et la tablette visuo-spatiale, responsable du traitement de l'information non verbale, visuelle ou spatiale. La boucle phonologique comprend deux composantes distinctes dont la boucle articulatoire et le registre phonologique. L'information serait passivement emmagasinée dans le registre phonologique où elle est maintenue active pendant environ deux secondes avant de s'estomper. La boucle articulatoire, qui est basée sur l'articulation, serait responsable de recirculer ou d'autorépéter l'information contenue dans le registre phonologique afin de la maintenir active en mémoire. Selon Logie, le fonctionnement de la tablette visuo-spatiale est analogue à celui de la boucle phonologique : le scribe interne serait responsable d'autorépéter l'information visuelle entreposée passivement dans le cache visuel. Baddeley (1986) suggère que le scribe interne est lié au mouvement des yeux. Cependant, le rôle exact du mouvement oculaire lors de la rétention de l'information spatiale fait encore l'objet de plusieurs études (p. ex., Lawrence, Myerson, & Abrams, 2004).

L'approche modulaire est notamment appuyée par la démonstration de doubles dissociations entre le traitement de l'information verbale et le traitement de l'information spatiale (p. ex., Farmer et al., 1986; Meiser & Klauer, 1999; Smith et al., 1996). Par exemple, lors d'une tâche de reconnaissance spatiale, les participants doivent indiquer si une localisation donnée fait partie d'un ensemble de localisations en mémoire. À l'aide de

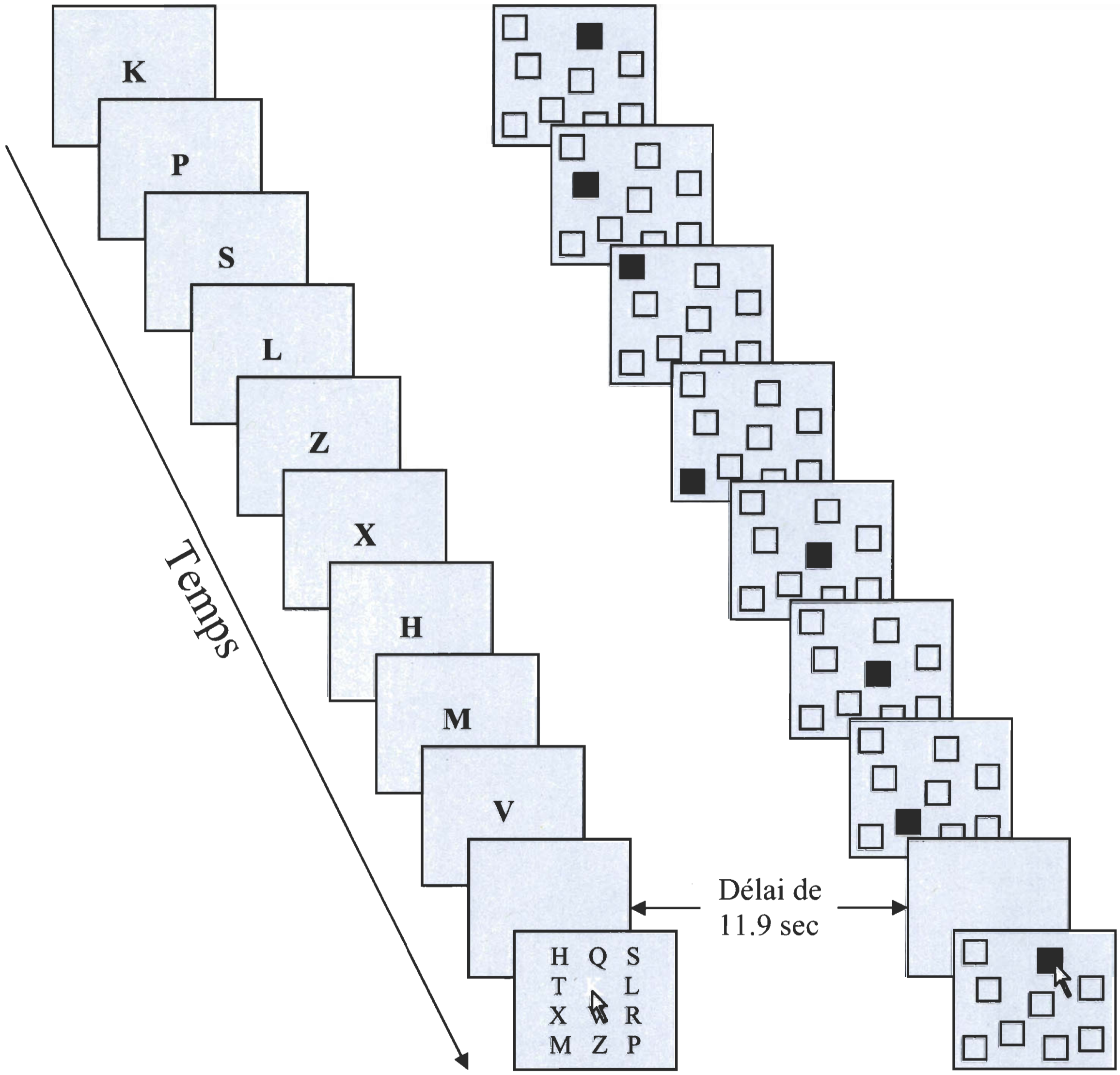

Figure 1. Illustration de la tâche de rappel verbal (gauche) et de la tâche de rappel spatial (droite) utilisées dans l'étude de Meiser et Klauer (1999).

la neuroimagerie, Smith et al. montrent que l'exécution d'une telle tâche active principalement l'hémisphère droit. Lors de l'exécution d'une tâche analogue de reconnaissance verbale cependant, l'hémisphère gauche est davantage activé. Ces résultats suggèrent que des modules différents sont responsables de la rétention de l'information verbale et spatiale. Un autre exemple de double dissociation est rapporté par l'étude de

Meiser et Klauer. Ces auteurs utilisent des tâches de rappel sériel dans lesquelles les participants doivent rappeler l'ordre où des séries d'items ont été présentées (voir Figure 1). Dans la tâche verbale, des séquences de neuf lettres sont présentées. Dans la tâche spatiale, une version informatisée des blocs de Corsi (voir Corsi, 1972; Milner, 1971), les participants doivent reconstituer l'ordre dans lequel des séquences de sept localisations spatiales ont été présentées. La frappe cadencée, une activité spatiale qui consiste à appuyer séquentiellement sur les touches de *1* à *9* du clavier numérique, et la suppression articulatoire, une activité verbale où les participants doivent articuler les lettres de *a* à *g*, sont utilisées en concomitance avec les tâches de mémoire. Meiser et Klauer observent que la frappe cadencée affecte davantage la performance aux blocs de Corsi qu'à la tâche de mémoire verbale alors que la suppression articulatoire interfère sélectivement avec le rappel verbal (voir aussi Farmer et al., 1986; Logie, Zucco, & Baddeley, 1990; Salway & Logie, 1995). La démonstration que l'interférence survient lorsque des stimuli de même nature sont utilisés dans deux tâches exécutées simultanément suggère que les mécanismes en mémoire sont spécifiques au type de stimuli traités.

L'APPROCHE UNITAIRE

Une approche unitaire soutient que les processus responsables de la rétention sont communs à tous les types d'information, plutôt que de faire appel à des modules indépendants (Cowan, 1993; Crowder, 1982; Jones, 1993). Par exemple, Cowan (1993) suggère que la MCT est une portion activée de la mémoire à long terme. Ainsi, lorsque des items à mémoriser sont présentés, les caractéristiques correspondantes sont activées en mémoire à long terme. Ce modèle est unitaire puisqu'il propose que les items sont activés indépendamment de la modalité et du type d'information présentée (voir aussi Nairne, 1990). Une autre vision unitaire est véhiculée par Jones et ses collaborateurs selon qui la rétention de l'information est assurée par un ensemble de processus plutôt que par un assortiment de modules (voir Jones, 1993; Jones et al., 2006; Jones, Beaman, & Macken, 1996; Jones, Macken, & Nicholls, 2004). Selon Jones et ses collaborateurs, la performance dans une tâche de mémoire dépend en partie de la capacité du système perceptif à organiser l'information perçue en un tout cohérent. Cette idée est similaire aux principes de la Gestalt selon lesquels les objets tendent à être regroupés en fonction de leur proximité ou de leur ressemblance. Ainsi, la rétention serait fonction du niveau de cohérence perçue dans l'ensemble d'items présentés. Jones et al. (2004, 2006) suggèrent que les processus perceptifs interagissent avec les processus de planification du mouvement afin de coordonner un ensemble de gestes qui permettront de reproduire physiquement la séquence (*embodiment*). Par exemple, lorsqu'une série de mots est présentée aux participants, ces mots sont tout d'abord organisés en une séquence ordonnée de représentations acoustiques (processus perceptifs). Ces représentations sont ensuite utilisées afin de planifier la série de gestes articulatoires qui permettra de reproduire les caractéristiques acoustiques de la séquence. La rétention d'une série de mots dépend donc de l'efficacité des processus de planification du mouvement à coordonner les gestes qui permettront d'articuler la séquence.

L'approche unitaire est appuyée par la démonstration de patrons de performance équivalents entre le traitement de l'information spatiale et celui de l'information verbale (p. ex., Jones et al., 1995). Par exemple, lors d'une tâche de rappel sériel verbale, les participants doivent rappeler une série de chiffres dans l'ordre où ils ont été présentés. Les résultats montrent une courbe de positions sérielles où les premiers (effet de primauté) et les derniers (effet de récence) items de la liste sont mieux rappelés que les items médians (Beaman & Jones, 1998; Roodenrys & Quinlan, 2000; Saint-Aubin & Poirier, 2000). Cette courbe de positions sérielles typique est aussi rapportée lorsque l'information à rappeler est de nature spatiale (Avons, 1998; Farrand, Parmentier, & Jones, 2001; Parmentier & Jones, 2000; Smyth & Scholey, 1996; Ward et al., 2005). Plusieurs effets très robustes associés à la rétention de l'information verbale sont aussi reproduits lors de la rétention de l'information spatiale. Par exemple, l'effet suffixe, soit l'abolition de l'effet de récence par la présence du chiffre « 0 » inséré à la suite d'une séquence de chiffres à rappeler (Balota & Engle, 1981), est aussi observé lorsqu'un point noir à ignorer est présenté à la fin d'une séquence de points noirs dont la position spatiale et temporelle sont à mémoriser (Parmentier, Tremblay, & Jones, 2004). De plus, la performance globale est diminuée si des items à ignorer sont interpolés entre des items à rappeler, que ces items soient des mots (Baddeley, Papagno, & Andrade, 1993) ou des points dans l'espace (Tremblay, Nicholls, Parmentier, & Jones, 2005).

Alors que les dissociations entre la rétention de l'information verbale et celle de l'information spatiale ont traditionnellement été interprétées comme étant un appui à la vision modulaire (p. ex., Baddeley & Hitch, 1974), la démonstration de phénomènes équivalents entre les deux domaines supporte une approche unitaire (p. ex., Jones et al., 2006). La démonstration de dissociations et de similitudes fonctionnelles en MCT semble donc contradictoire. Cependant, la comparaison entre la rétention de l'information verbale et celle de l'information spatiale est souvent faite entre les études : les tâches verbales et spatiales sont donc rarement équivalentes. L'objectif du Chapitre II est donc de comparer directement la rétention de l'information verbale et la rétention de l'information spatiale à l'aide de tâches équivalentes afin de vérifier si les mêmes processus sont sollicités lors de la rétention de ces deux types d'information.

LA RÉTENTION DE L'INFORMATION

Que la mémoire soit conçue comme une collection de modules (voir p. ex., Baddeley, 1986) ou comme un ensemble de processus communs à tous les types d'information (voir p. ex., Jones et al., 2004), l'autorépétition joue un rôle central dans la rétention de l'information. L'approche modulaire soutient que l'autorépétition permet de rafraîchir la trace des items entreposés passivement dans un registre afin de les maintenir à un certain niveau d'activation (p. ex., Baddeley, 1986; Baddeley & Hitch, 1974). Lorsque l'autorépétition est moins efficace, plus d'erreurs sont commises parce que davantage de représentations en mémoire s'estompent. L'approche unitaire quant à elle, conçoit l'autorépétition comme une stratégie permettant de reconstruire la séquence d'items afin de leur imposer une structure où leur ordre d'apparition sera préservé (voir p. ex., Jones et al., 2004, 2006). Les erreurs surviennent lors de la planification de la séquence motrice, lorsque les gestes permettant de reproduire la séquence sont plus difficiles à coordonner. Alors que la nature de l'autorépétition verbale est bien définie (p. ex., Baddeley, Thomson, & Buchanan, 1975), la nature de l'autorépétition spatiale a été beaucoup moins étudiée (Parmentier, Elford, Maybery, 2005).

LA RÉTENTION DE L'INFORMATION VERBALE

Dans le domaine verbal, les processus de planification et de production du langage semblent jouer un rôle important dans la rétention de l'information (Gathercole & Baddeley, 1993). Cette hypothèse est appuyée par un ensemble d'études qui démontrent que l'efficacité avec laquelle une séquence d'items est articulée est un indice important de la performance dans une tâche de rappel (voir p. ex., Baddeley et al., 1975; Murray & Jones, 2002; Schweickert & Boruff, 1986; Woodward, Macken, & Jones, 2008). Par exemple, Baddeley et al. rapportent que les mots longs sont plus difficiles à rappeler que les mots courts (l'effet de longueur du mot). Si l'articulation est bloquée à l'aide d'une tâche de suppression articulatoire pendant laquelle les participants doivent prononcer à voix haute des items non pertinents, l'avantage des mots courts par rapport aux mots longs disparaît, suggérant que cet avantage est lié à l'articulation. De plus, certaines études montrent que lorsque les transitions entre les mots d'une liste sont difficiles à articuler, la performance de rappel est plus faible que lorsque les transitions sont plus faciles à articuler[1] (Murray & Jones, 2002; Woodward et al., 2008). Ces résultats semblent donc indiquer que la performance de rappel dépend de l'efficacité avec laquelle les items à retenir sont articulés.

À l'appui du lien entre l'articulation et la rétention, il semble que les erreurs commises lors de l'articulation dans le langage normal soient très similaires aux erreurs commises lors d'une tâche de rappel verbal (voir p. ex., Acheson & MacDonald, 2009; Ellis, 1980; Page, Madge, Cumming, & Norris, 2007). L'effet de similitude phonologique selon lequel les items qui ont une phonologie similaire ont tendance à transposer, est aussi observé lorsque les participants doivent lire des listes de lettres similaires phonologiquement (p. ex., Page et al., 2007). Selon Ellis, ce phénomène observé dans le langage courant et connu sous le nom de *phonemic spoonerisms*, est fonctionnellement équivalent aux erreurs commises lors d'une tâche de mémoire, ce qui suggère que le système de production langagière soit relié à la rétention de l'information verbale (voir

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[1] Une transition est plus difficile à articuler lorsqu'elle implique un changement au niveau du lieu d'articulation. Par exemple, la transition entre les mots « doute » et « cap » implique le passage d'une consonne dental (t) dont le lieu d'articulation se situe au niveau des dents, à une consonne vélaire (k) dont le lieu d'articulation se situe à l'arrière du palais. Une transition facile à articuler implique un changement du lieu d'articulation nul ou faible, comme la transition entre les mots « chic » et « gant », « k » et « g » étant toutes deux des consonnes vélaires.

aussi Acheson & MacDonald, 2009; Jones et al., 2004, 2006). La relation étroite entre l'articulation et la rétention de l'information verbale suggère que ces deux fonctions sont assurées par un seul et même système (p. ex., Acheson & MacDonald, 2009; Ellis, 1980).

LA RÉTENTION DE L'INFORMATION SPATIALE

Alors que la planification du langage joue un rôle important lors de la rétention de l'information verbale, la nature des processus impliqués lors de la rétention de l'information spatiale sont moins bien connus. Certaines études suggèrent que l'autorépétition spatiale est reliée au déplacement attentionnel (p. ex., Awh & Jonides, 1998, 2001; Awh, Jonides, & Reuter-Lorenz, 1998; Smyth, 1996). Par exemple, à l'aide de la neuroimagerie, Awh et Jonides (2001) démontrent que les aires du cerveau activées par le déplacement de l'attention dans l'espace et celles activées lors d'une tâche de mémoire spatiale se chevauchent. Awh et al. montrent aussi que lorsque les participants doivent déplacer leur attention à un endroit différent de la localisation à maintenir en mémoire, leur capacité à relocaliser l'item mémorisé est altérée.

D'autres chercheurs suggèrent que le mouvement oculaire joue un rôle clé lors de la rétention de l'information spatiale (p. ex., Lawrence, et al., 2004; Lawrence, Myerson, Oonk, & Abrams, 2001; Pearson & Sahraie, 2003; Tremblay et al., 2006). Dans le domaine de la mémoire, il existe une relation étroite entre le mouvement oculaire et la performance de rappel. Par exemple, plus les items sont fixés longtemps, plus il est facile de les reconnaître ou de les rappeler (p. ex., Hollingworth & Henderson, 2002; Saint-Aubin, Tremblay, & Jalbert, 2007; Zelinsky & Loschky, 2005). Plusieurs études ont donc été menées afin de déterminer le rôle du déplacement oculaire dans la rétention de l'information spatiale. Par exemple, Pearson et Sahraie (2003) ont inséré un intervalle de rétention entre la présentation de la séquence et le rappel lors d'une tâche des blocs de Corsi. Au cours de l'intervalle de rétention, les participants doivent autorépéter la séquence afin de maintenir les localisations en mémoire. Dans une condition interférente, le mouvement des yeux est bloqué à l'aide d'une tâche de poursuite visuelle où les participants doivent suivre des yeux une cible qui se déplace à l'écran. Les résultats montrent que la tâche de poursuite visuelle interfère avec le rappel des localisations spatiales en mémoire. Dans une autre étude, Tremblay et al. insèrent un intervalle de rétention lors d'une tâche de rappel sériel spatiale analogue aux blocs de Corsi. Une analyse du mouvement oculaire indique que les localisations en mémoire affectent directement la planification du mouvement des yeux : les participants tendent à fixer les points dans l'ordre où ils ont été présentés. Plus l'ordre dans lequel les points sont fixés est similaire à l'ordre dans lequel ils ont été présentés, plus la performance de rappel est élevée. Ces résultats suggèrent que l'autorépétition spatiale est reliée à la planification du mouvement oculaire (voir aussi Baddeley, 1986). Ainsi, afin de retenir une série de localisations spatiales, les participants déplaceraient les yeux de localisation en localisation.

Si le mouvement oculaire joue un rôle important dans l'autorépétition spatiale, les facteurs qui affectent l'efficacité avec laquelle les yeux sont déplacés devraient aussi affecter la mémoire. Un des facteurs qui influencent l'efficacité du mouvement oculaire est la distance. Abrams, Meyer et Kornblum (1989) démontrent que lorsque les participants bougent les yeux entre deux localisations visibles à l'écran, la vitesse et la précision du déplacement oculaire diminuent en fonction de l'augmentation de la distance entre les localisations. De plus, les résultats de Parmentier et ses collaborateurs (Parmentier et al., 2005, 2006) indiquent que la distance qui sépare les localisations successives d'une séquence à mémoriser est négativement reliée à la performance (l'effet de longueur des sentiers). Cependant, les études actuelles ne permettent pas de déterminer si cet effet est relié à l'efficacité avec laquelle les yeux sont déplacés entre les localisations. Dans le Chapitre III, l'effet de longueur des sentiers est étudié à l'aide de l'analyse du mouvement oculaire et de l'utilisation d'une tâche de suppression oculaire afin d'étudier la nature des processus responsables de la rétention de l'information spatiale.

STRATÉGIE MÉTHODOLOGIQUE

Les tâches utilisées dans la thèse sont le rappel sériel (p. ex., Conrad, 1964; Hitch, Fastame, & Flude, 2005) et la reconstruction de l'ordre (p. ex., Jones et al., 1995; Smyth & Scholey, 1994). Lors d'une tâche de rappel sériel, une séquence d'items est présentée aux participants. Leur tâche est de rappeler les items ainsi que leur ordre d'apparition. Lors d'une tâche de reconstruction de l'ordre, seule la procédure de rappel est différente. Après la présentation de la séquence, l'identité de tous les items est fournie et les participants doivent les sélectionner dans leur ordre de présentation. Alors que la reconstruction de l'ordre sollicite principalement la mémoire de l'ordre, la performance en rappel sériel dépend du rappel de l'ordre ainsi que du rappel des items qui ont été présentés (voir Neath, 1997).

Dans le domaine spatial, plusieurs chercheurs utilisent une version informatisée des blocs de Corsi (p. ex., Avons, 2007; Meiser & Klauer, 1999; Smyth & Scholey, 1994, 1996; voir Figure 1). Dans cette version de la tâche, les items à mémoriser sont tirés d'un ensemble fixe de neuf localisations, souvent représentés par des blocs qui sont visibles pendant toute la durée de l'expérience. Dans la thèse, la tâche de points (Jones et al., 1995), une variante des blocs de Corsi, est utilisée. Dans la tâche de points, les marqueurs de localisations sont des points noirs qui apparaissent et disparaissent séquentiellement à l'écran (Figure 2A). Cette version comporte un avantage comparativement aux blocs de Corsi, soit la flexibilité allouée par le fait de ne pas avoir un ensemble fixe de localisations (voir Parmentier et al., 2006). Ainsi, les localisations peuvent changer à chaque essai, ce qui minimise le risque que les participants utilisent une étiquette verbale pour les encoder. La tâche de points permet aussi de manipuler les caractéristiques des items (p. ex., la distance entre les localisations), ce qui n'est pas toujours possible avec un ensemble fixe de localisations. Finalement cette tâche permet de manipuler la procédure de rappel : il est possible de représenter l'ensemble des points afin de tester le rappel de l'ordre (reconstruction de l'ordre; Figure 2B), ou de demander aux participants de rappeler l'ordre ainsi que l'endroit où les items ont été présentés (rappel sériel; Figure 2B).

Dans la thèse, les processus impliqués lors de la rétention de l'information spatiale et verbale sont étudiés à l'aide de tâches verbales et spatiales équivalentes. L'utilisation de tâches équivalentes permet de s'assurer que les différences observées entre le traitement de l'information verbale et le traitement de l'information spatiale ne sont pas dues à des différences méthodologiques, mais bien au type d'information qui doit être traité lors de la tâche (voir p. ex., Ward et al., 2005). Lors des tâches verbales, des séries de mots à basse fréquence (une à 19 occurrences par million) sont présentés séquentiellement à l'écran

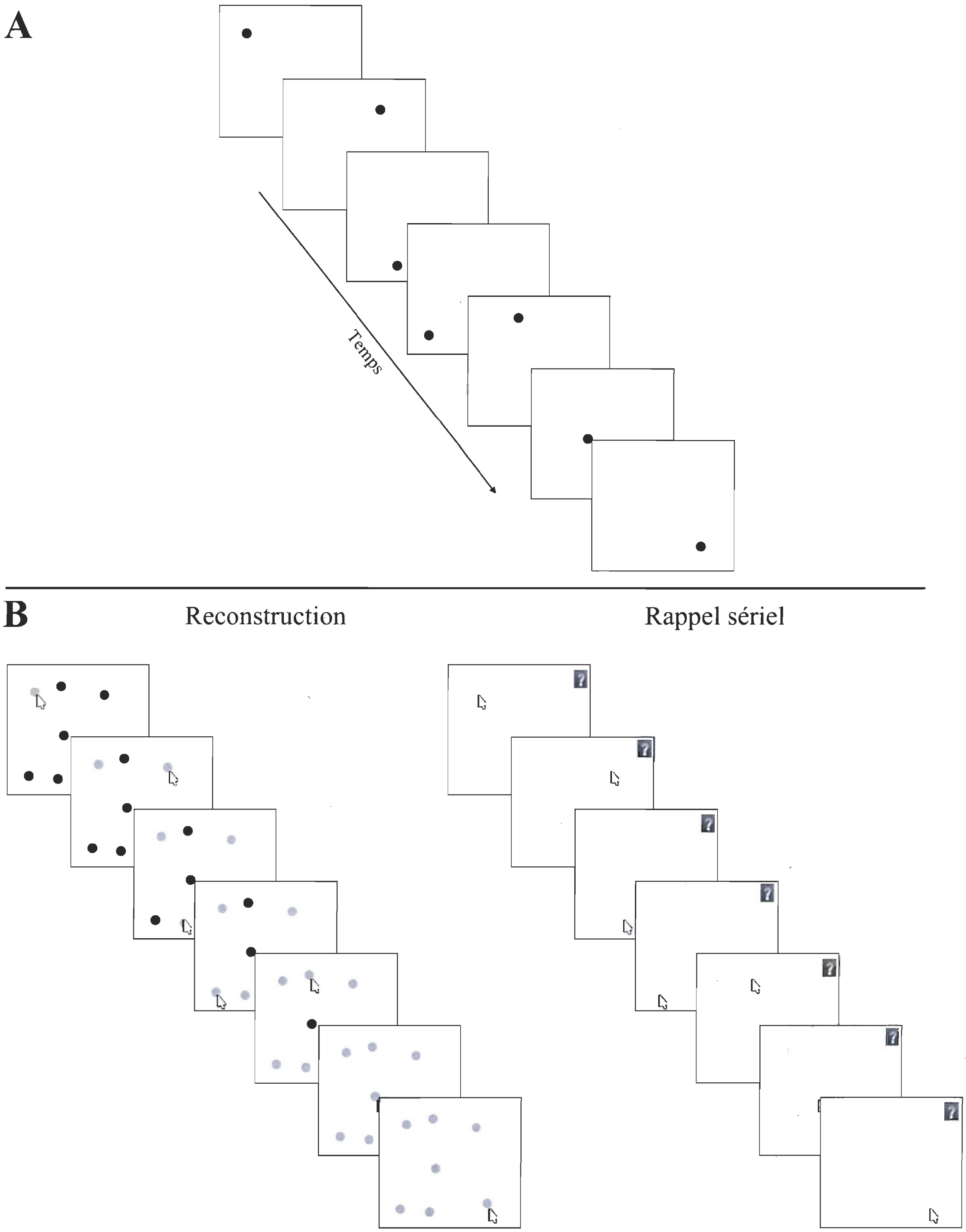

Figure 2. Schéma des tâches spatiales. Le panneau A illustre la présentation de la séquence. Le panneau B montre la procédure de rappel dans la tâche de reconstruction de l'ordre (gauche) et dans la tâche de rappel sériel (droite). Le point d'interrogation dans la tâche de rappel sériel peut être sélectionné lorsque les participants veulent omettre une réponse.

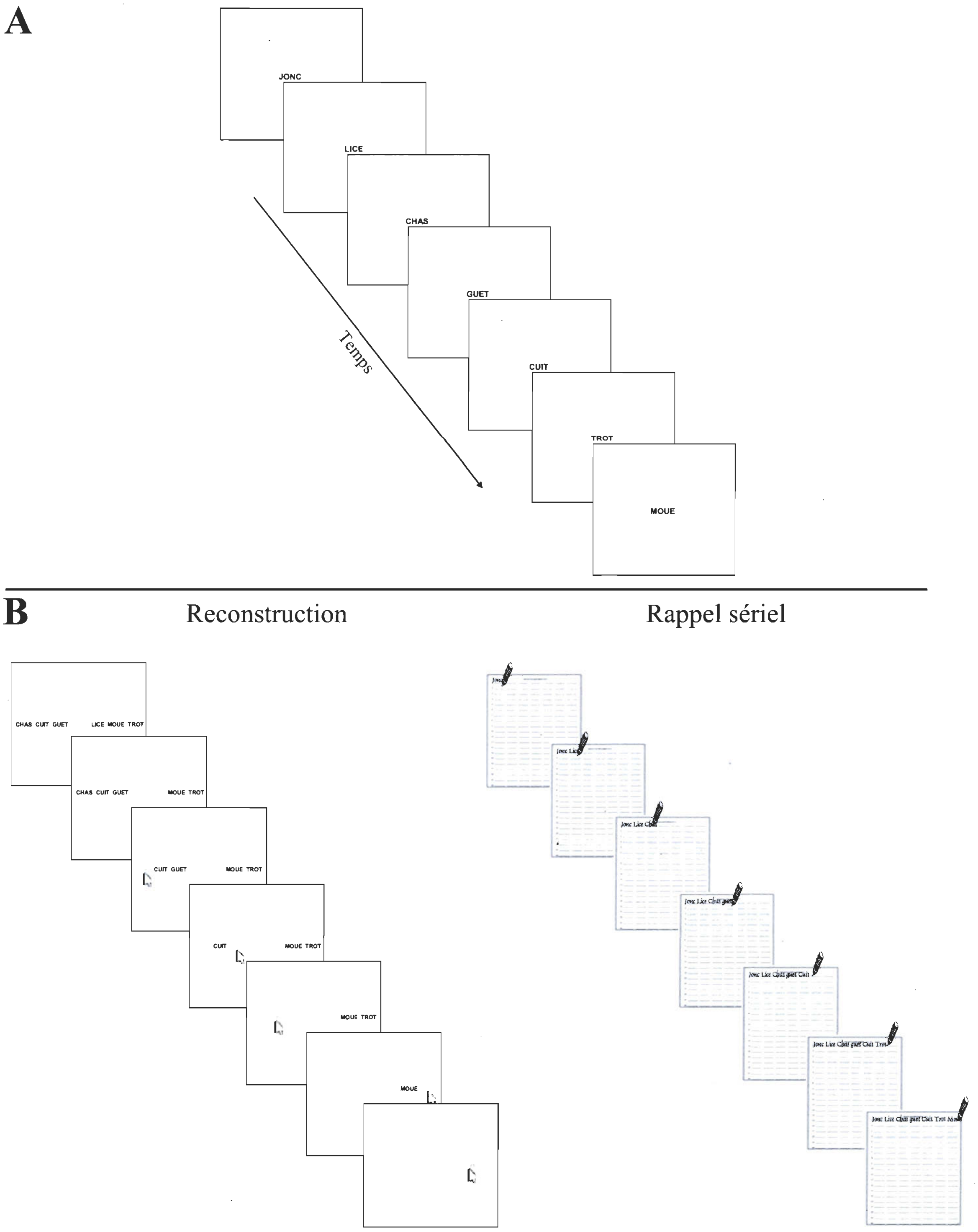

Figure 3. Schéma des tâches verbales. Le panneau A illustre la présentation de la séquence. Le panneau B montre la procédure de rappel dans la tâche de reconstruction de l'ordre (gauche) et dans la tâche de rappel sériel (droite).

(Figure 3A). Dans la tâche de reconstruction de l'ordre, les mots sont représentés à l'écran au moment du rappel afin que les participants puissent reconstituer l'ordre de la séquence (Figure 3B). Dans la tâche de rappel sériel, les participants doivent rappeler les mots qui ont été présentés en les écrivant sur une feuille dans le même ordre où ils sont apparus (Figure 3B). Ainsi, la seule différence entre les tâches verbales et spatiales est le type de stimuli qui doit être mémorisé.

L'utilisation de tâches verbales et spatiales équivalentes permet donc de comparer les processus en jeu lors de la rétention de ces types d'information. Pour ce faire, une analyse approfondie des erreurs commises lors des tâches de mémoire est réalisée. En effet, le type d'erreurs commises est très révélateur des processus sollicités au cours d'une tâche. Par exemple, les erreurs ont été mesurées afin de déterminer l'intégrité de la trace mnésique et la contribution de la mémoire à long terme lors de la rétention de mots fréquents et non fréquents (voir Saint-Aubin & Poirier, 2005). L'analyse du patron d'erreurs s'avère donc un outil de choix afin d'étudier les processus impliqués dans une tâche de mémoire et de vérifier si les mêmes processus sont sollicités lors de la rétention de l'information verbale et spatiale. Dans le Chapitre II, plusieurs erreurs sont mesurées. Par exemple, les participants peuvent omettre une réponse (omission), rappeler un item qui n'a pas été présenté dans la séquence (intrusion) ou rappeler un item dans la mauvaise position sérielle (transposition). De plus, l'effet de l'interférence verbale et spatiale sur les patrons d'erreurs est examiné. Deux activités, l'une de nature verbale et l'autre de nature spatiale, sont effectuées en concomitance avec les tâches de mémoire. Lors de l'activité verbale, la suppression articulatoire, les participants doivent prononcer les lettres A – B – C – D de façon continue pendant la présentation des items. Lors de l'activité spatiale, la frappe cadencée, les participants doivent toucher quatre blocs en alternance sans arrêt jusqu'au moment du rappel (voir Figure 4). L'utilisation d'une telle procédure permet de reproduire une double dissociation et de vérifier si l'interférence observée dans les tâches verbales et spatiales est attribuable à des processus similaires ou différents.

Finalement, afin de mieux comprendre la nature des processus responsables de retenir l'information spatiale, l'effet de longueur des sentiers est étudié dans une tâche de

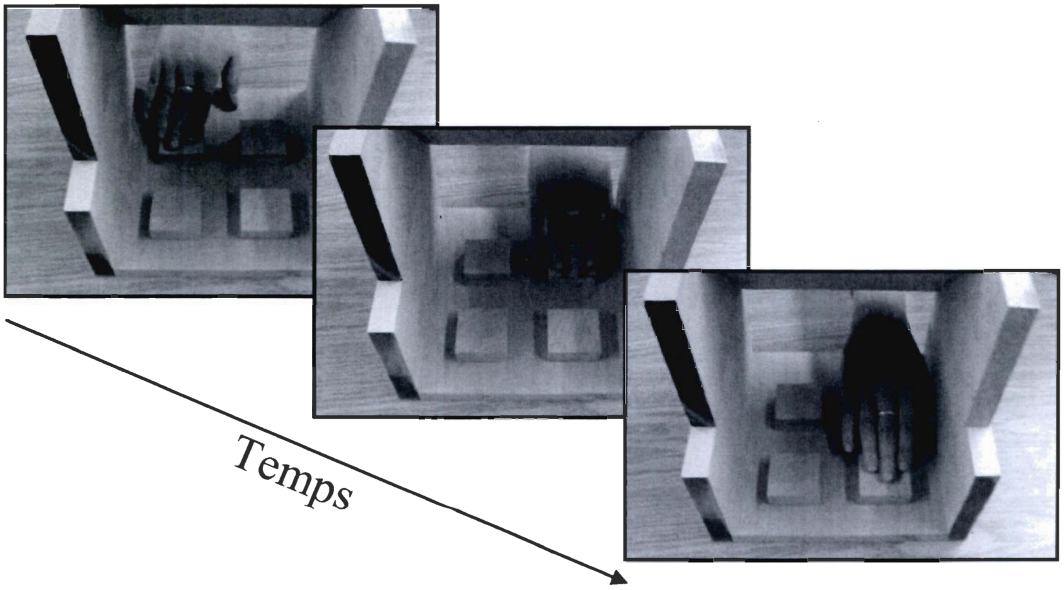

Figure 4. Illustration de la tâche de frappe cadencée.

reconstruction de l'ordre spatiale (p. ex., Parmentier et al., 2006). La distance entre les localisations successives est manipulée de sorte que la moitié des essais est caractérisée par des sentiers courts alors que l'autre moitié est caractérisée par des sentiers longs. Une tâche de suppression oculaire au cours de laquelle le mouvement des yeux est supprimé, ainsi que l'analyse du mouvement oculaire sont utilisées afin de vérifier si le mouvement des yeux est relié à l'effet de longueur des sentiers. L'analyse du mouvement oculaire est utilisée dans plusieurs études afin de mieux comprendre les processus sous-jacents au traitement de l'information spatiale (p. ex., Saint-Aubin et al., 2007; Tremblay et al., 2006; Zelinsky & Loschky, 2005) et s'avère donc un outil essentiel dans la thèse afin de mieux comprendre le lien entre le mouvement des yeux et la mémoire. Dans la thèse, le mouvement oculaire est mesuré à l'aide d'un appareil d'enregistrement des mouvements oculaires intégré à l'écran d'ordinateur sur lequel les stimuli sont présentés (voir Figure 5). Le mouvement oculaire est enregistré pendant la présentation des points ainsi que pendant un intervalle de rétention au cours duquel le participant doit autorépéter la séquence. La durée de fixation sur chaque point et l'ordre dans lequel ces points sont fixés sont mesurés.

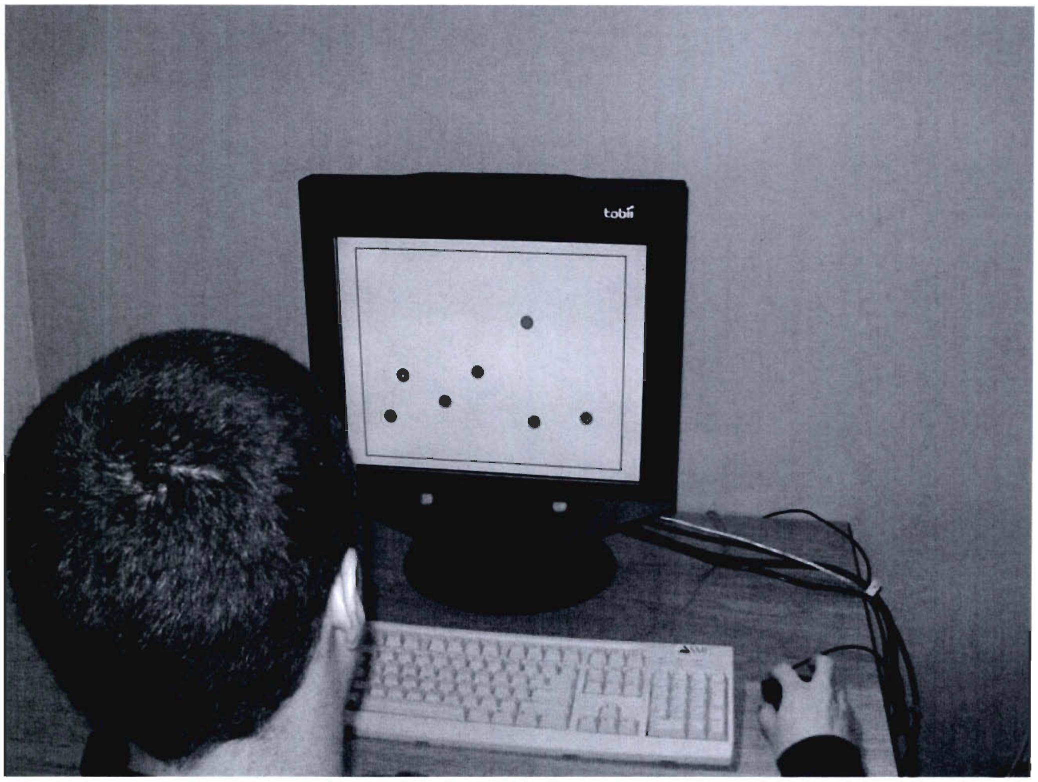

Figure 5. Appareil utilisé pour l'enregistrement du mouvement oculaire. Une caméra circulaire est intégrée au bas de l'écran.

PLAN DE LA THÈSE

L'objectif général de la thèse est de caractériser les processus impliqués lors de la rétention de l'information verbale et spatiale afin de vérifier si ces processus sont communs à la rétention de tous les types d'information ou si la rétention de l'information fait appel à des composantes spécifiques. Dans un premier temps, les processus impliqués lors de la rétention de l'information verbale et spatiale sont comparés directement (Chapitre II). Pour ce faire, une procédure de double dissociation ainsi qu'une analyse approfondie des erreurs sont utilisées lors de tâches de mémoire verbales et spatiales équivalentes. Par la suite, la nature des processus moins connus impliqués lors de la rétention de l'information spatiale est étudiée (Chapitre III). L'effet de longueur des sentiers est examiné à l'aide de l'analyse du mouvement oculaire et d'une tâche de suppression oculaire afin de déterminer si l'efficacité avec laquelle les yeux sont déplacés affecte la mémoire des localisations. Les démonstrations à l'appui des approches modulaires et unitaires sont ensuite revisitées et expliquées à la lumière d'une nouvelle approche théorique (Chapitre IV). Finalement, les résultats de la thèse sont discutés afin de déterminer si les mêmes processus sont impliqués lors de la rétention de l'information spatiale et verbale (Chapitre V).

CHAPITRE II

REVISITER LES SIMILITUDES ET LES DISSOCIATIONS EN MÉMOIRE

RÉSUMÉ

L'objectif du Chapitre II est de comparer directement la rétention de l'information verbale et spatiale en examinant les différents patrons d'erreurs commises dans des tâches de mémoire spatiales et verbales équivalentes. Dans l'Expérience 1, les patrons d'intrusions, d'omissions, de transpositions et de *fill-ins* (voir Henson, 1996) produits lors de tâches de rappel sériel et de reconstruction spatiales et verbales sont comparés. Dans l'Expérience 2, l'effet de la suppression articulatoire et de la frappe cadencée sur les patrons d'erreurs produits en reconstruction verbale et spatiale est évalué. Les résultats indiquent que la suppression articulatoire interfère sélectivement avec la mémoire verbale alors que la frappe cadencée interfère sélectivement avec la mémoire spatiale. De plus, lorsque les tâches sont équivalentes, les patrons d'erreurs sont similaires entre le traitement de l'information verbale et le traitement de l'information spatiale. L'ensemble de ces résultats est discuté à la lumière des modèles prédominants de la mémoire.

REVISITING EVIDENCE FOR MODULARITY AND FUNCTIONAL EQUIVALENCE ACROSS VERBAL AND SPATIAL DOMAINS IN MEMORY

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ABSTRACT

Evidence in favour of modularity and of functional equivalence between the processing of verbal and spatial information in short-term memory was revisited. This was done by investigating the patterns of intrusions, omissions, transpositions and fill-ins in verbal and spatial serial recall and order reconstruction tasks, under control, articulatory suppression and spatial tapping conditions. We observed that when tasks were fully equated, all patterns of errors were equivalent between the verbal and spatial domains. Moreover, articulatory suppression interfered more with the verbal memory tasks than with the spatial memory tasks. This interference was mostly due to an increase of omissions and transpositions. Similarly, tapping was more disruptive of spatial memory than of verbal memory tasks, and affected primarily the number of omissions and transpositions. The patterns of errors and their interaction with interference are discussed in light of the predominant approaches to modeling memory and provide a rich set of data for modeling efforts.

INTRODUCTION

A central question addressed by many researchers in the domain of cognitive psychology is whether short term memory (STM) mechanisms are modular or not. The presence of dissociations between the processing of spatial and that of verbal information points to the possibility of modularity in STM (e.g., Farmer, Berman, & Fletcher, 1986; Smith, Jonides, & Koeppe, 1996). For example, when activity *a* interferes with task *A* but not with task *B*, and that activity *b* interferes with task *B*, but not with task *A*, researchers usually conclude that tasks A and B are dependent on two distinct modules (see Baddeley, 2003; Brown & Lamberts, 2003). There is also evidence of functional equivalence in STM such as the extension of classical verbal memory phenomena to the spatial domain (e.g., Jones, Farrand, Stuart, & Morris, 1995; Smyth & Scholey, 1996; Ward, Avons, & Melling, 2005). Evidence of dissociations led to a modular account of STM with separate verbal and visual-spatial systems, the Working Memory Model (Baddeley, 1986, 2001; Baddeley & Hitch, 1974; see also Logie, 1995), whereas evidence of equivalence promoted more unitary accounts of memory (e.g., Brown, Neath, & Chater, 2007; Crowder, 1993; Jones, Beaman, & Macken, 1996; Jones, Hughes, & Macken, 2006).

There is a large gap between those two opposing theoretical views and, at an empirical level, functional dissociations and similarities are difficult to reconcile. Indeed, methodologies vary considerably and most often, comparisons between the verbal and spatial domains are made across studies. One key observation is that dissociations seem to take place when STM task requirements emphasize on the processing of item information, such as in item recognition where the participants are asked to indicate if an item is new or was part of to-be-remembered (TBR) list (e.g., Farmer et al., 1986; Smith et al., 1996). Functional equivalence however, seem to emerge from tasks in which retention of serial order alone is required, such as in order reconstruction where the participants have to reproduce the order in which series of items were presented (e.g., Jones et al., 1995; Ward et al., 2005). Thus, different processes may be responsible for the observed dissociations and functional similarities. The goal of the present series of experiments is two-fold. The first objective was to revisit the evidence for functional equivalence and modularity by adopting a double-dissociation procedure, with an in-depth analysis of errors. In line with the idea that the different types of errors represent the functioning of different STM mechanisms (such as for the processing of item and order information), the second objective was to provide a rich set of data that will allow constraining the different models of STM (e.g., Henson, 1998; Farrell & Lewandowsky, 2002).

EVIDENCE FOR MODULARITY

An empirical observation that is often reported as a manifestation of the fractionation of STM is a dissociation between the verbal and spatial domains. Such dissociations were reported, in part, in the context of neuroimaging studies. For example, Smith et al. (1996) used positron emission tomography (PET) during verbal and spatial recognition tasks involving item processing. Participants were asked to indicate whether an item – a location in the spatial task and a letter in the verbal task – was part of a memorised set of stimuli or was a novel item. Smith et al. observed that the regions activated during the verbal task were principally located in the left hemisphere whereas the right hemisphere was activated during the spatial task (see also Awh et al., 1996)

A dissociation between the verbal and spatial domains was also observed by Logie, Zucco, and Baddeley (1990). In the spatial task, the participants had to indicate which square of a square matrix pattern differed from a previously presented matrix. In the verbal task, a sequence of letters was first presented. Following presentation, the participants had to identify which letter from an array of letters was not in the preceding series. Despite the sequential presentation, no order information had to be recalled in these tasks. Logie et al. demonstrated that mental arithmetic interfered more with the verbal than spatial task, whereas spatial mental imagery was more disruptive during the spatial than verbal task (see also Farmer et al., 1986).

Another study by Meiser and Klauer (1999) reported dissociations between the verbal and spatial domains using order reconstruction tasks in which some item information must also be retrieved. In verbal reconstruction, sequences of nine letters were presented. For recall, the participants had to select which items had been presented and place them in their order of presentation. The spatial analogue was a computerised version of the Corsi blocks, where the participants had to reproduce the order in which sequences of seven spatially distributed blocks had been presented. Meiser and Klauer observed that spatial tapping was more disruptive for the Corsi blocks than for verbal serial recall, and that articulatory suppression was more disruptive for verbal serial recall than for the Corsi blocks (see Salway & Logie, 1995). In these tasks, item memory was required since the participants had to select the nine – or seven – correct items from a pool of twelve – or nine – items. Memory for order was also called for since the ordered recall of the items was required. However, the contribution of item and order memory to the dissociation was not examined. Moreover, the spatial and verbal tasks were not equivalent since in the Corsi blocks, all items were visible to the participants during the whole experiment whereas in verbal serial recall, the items disappeared following their presentation.

EVIDENCE OF FUNCTIONAL EQUIVALENCE

Several studies suggested that the processing of verbal and that of spatial information is functionally equivalent by demonstrating the presence of similarities between the two domains, mainly when order processing was involved. For example, serial position curves with primacy and recency effects very typical in the verbal literature (Beaman & Jones, 1998; Saint-Aubin & Poirier, 2000) are also obtained in the spatial domain (Avons, 1998; Farrand, Parmentier, & Jones, 2001; Nairne & Dutta, 1992; Parmentier & Jones, 2000; Smyth & Scholey, 1996). Moreover, when the two domains are compared directly using the same procedure – such as order reconstruction in which item processing is minimal (see Neath, 1997) – the results fail to show an interaction between stimulus domain and serial position, suggesting that primacy and recency effects are equivalent in the verbal and spatial domains (Jones et al., 1995; see also Ward et al., 2005).

Another classical finding in the verbal literature is that when an item is recalled in the wrong serial position it is recalled near the position in which it was presented (e.g., Conrad, 1964; Estes, 1972). For example, if the sequence 1234567 is presented and item 1 is recalled in the wrong serial position, the probability for this item to be recalled at the second serial position is higher than that to be recalled at the third or fourth serial position. When the proportion of transpositions is plotted against the migration distance – the distance separating the recalled item from the position in which it was presented – the proportion of transpositions decreases as a function of migration distance in the spatial (Parmentier & Jones, 2000; Smyth & Scholey, 1996) and verbal domains (e.g., Brown, Preece, & Hulme, 2000). Several other phenomena useful in understanding the mechanisms involved in the processing of verbal information were also extended to the spatial domain (e.g., see Jones et al., 1995; Tremblay, Nicholls, Parmentier, & Jones, 2005; Turcotte, Gagnon, & Poirier, 2005).

THE PRESENT STUDY

Although a large number of studies have provided evidence for modularity and functional equivalence across domains and provided support for two opposite views, some constraints may limit their interpretation. First, the processing of spatial information has typically been examined using order reconstruction (e.g., Avons, 1998; Jones et al., 1995; Parmentier, Tremblay, & Jones, 2004; Tremblay et al., 2005), whereas the use of serial recall is more common in the verbal domain (e.g., Beaman & Jones, 1998; Hitch, Fastame, & Flude, 2005). Both tasks measure serial order processing, however, order reconstruction is often considered to be a purer test of order retention: participants must recall both item and order information in serial recall, whereas in order reconstruction, item information is re-presented to the participants so that they only have to recall their order (see Neath, 1997, for a discussion). In Experiment 1, serial recall and reconstruction tasks were directly compared in order to verify whether the same processes are solicited in both tasks. Also, in most studies, double dissociations and functional similarities were examined using the overall performance (e.g., see Farmer et al., 1986) or the proportion correct plotted as a function of serial position (e.g., see Jones et al., 1995; Meiser & Klauer, 1999). However, errors may result from different sources: an error can occur because the participant has forgotten the items' identity, or because the correct item was recalled elsewhere in the series. How the different types of errors contribute to the presence of dissociations and functional similarities however, has yet to be systematically assessed. An analysis of errors is thus deemed necessary in order to establish whether the processing of spatial and that of verbal information is functionally equivalent since different patterns of errors may reflect the use of different STM mechanisms. Moreover, their interaction with interference will contribute to highlight the mechanisms responsible for producing double dissociations.

The Production of Errors and the Mechanisms of STM

The distribution of the different types of errors will provide crucial information in the endeavour to understand how information is retained over the short-term (Henson, 1996, 1998). The mechanisms or memory principles responsible for their production are reviewed below (see Table 1).

Omissions. When no item is recalled for a given serial position, an omission is committed. Omissions can occur when no representation is selected from memory because their level of activation is too low (Burgess & Hitch, 1999; Farrell & Lewandowsky, 2002;

Table 1

Models of STM and the mechanisms and principles they incorporate in order to account for the production of omissions, intrusions, transpositions, fill-ins and associates.

	Omissions	**Intrusions**	**Transpositions, Fill-ins & Associates**
Feature Model (Nairne, 1990; Neath, 1999)	Item similarity	Item marking Redintegration	Item marking Redintegration
OSCAR (Brown et al., 2000)	Item similarity	Item marking Redintegration	Item marking Primacy gradient
Phonological Loop Model (Burgess and Hitch, 1999)	Low activation	Item marking Redintegration	Item marking Primacy gradient
Primacy Model (Page & Norris, 1998)	Low activation	Redintegration	Primacy gradient
SIMPLE (Brown et al., 2007)	Item similarity	Item marking	Item marking Primacy gradient
SOB (Farrell & Lewandowsky, 2002)	Low activation	Primacy gradient	Primacy gradient
Start-End Model (Henson, 1998)	Low activation	Item marking Redintegration	Item marking Primacy gradient

Henson, 1998; Page & Norris, 1998) or when the memory representation is not distinct enough from the other memory representations to be selected as a response (e.g., Brown et al., 2000, 2007; Nairne, 1990).

Transpositions. A transposition occurs when an item is recalled in a different serial position from that in which it was presented. In positional models (e.g., Brown et al., 2000, 2007; Burgess & Hitch, 1999; Estes, 1997; Henson, 1998), each to-be-remembered item is associated with a contextual cue representing its position in the list (*item marking*, see Farrell & Lewandowsky, 2004). Because the contexts for adjacent items overlap, an incorrect item with a similar context may be cued and transpose during recall. Transpositions can also be produced when the wrong TBR item is reconstructed because of its similarity with the correct item (*redintegration;* see Lewandowsky, 1999; Nairne, 1990). Finally, order can also be maintained through the use of a primacy gradient combined with a response suppression mechanism, where each item is more strongly encoded – i.e. more distinct (Brown et al., 2007), more activated (Burgess & Hitch, 1999; Farrell & Lewandowsky, 2002; Page & Norris, 1998), or more strongly associated with its context (Brown et al., 2000; Henson, 1998) – than its successors.

Intrusions. An intrusion is committed when an item that had not been presented in the just presented sequence is recalled. In positional models, the items' position is generally coded on several dimensions, resulting in similar contexts for items presented in the same serial position in successive lists (Brown et al., 2007; Burgess & Hitch, 1999; Estes, 1997; Henson, 1998). During retrieval, an item that belongs to the preceding series may therefore be cued because of its similar context with the correct item (intra-list intrusions). Intrusions can also occur during redintegration when the wrong item is reconstructed due to its similarity with the correct item (extra-list intrusions; Brown et al., 2000; Burgess & Hitch, 1999; Henson, 1998; Nairne, 1990; Neath, 1999; Page & Norris, 1998).

Fill-ins and associates. When a transposition is committed, it can be followed by several types of responses (e.g., Henson, 1996; Surprenant, Kelley, Farley, & Neath, 2005). This response can be the correct item, the earliest item in the list that has not yet been recalled (a fill-in) or the item following the recalled item in the TBR list (an associate).

Item marking ensures that the correct response is always the most likely to be recalled, (e.g., Brown et al., 2000; Burgess & Hitch, 1999; Henson, 1998) whereas a primacy gradient predicts that during recall, the strongest representation – a fill-in – is more likely to be output (Brown et al., 2000; Burgess & Hitch, 1999; Farrell & Lewandowsky, 2002; Henson, 1998; Page & Norris, 1998).

The Choice of the Stimuli

In order to explore the similarities and differences between the spatial and verbal domains, it is important to choose stimuli that are comparable in memorability. In the present study, spatial stimuli consisted of spatially distributed dots and low frequency words were used as verbal stimuli[1]. The choice of the spatial stimuli was influenced by several factors. First, spatially distributed dots were preferred over visual matrices (e.g., Avons, 1998) or abstract visual shapes (e.g., Broadbent & Broadbent, 1981) because they allow greater flexibility. For example, visual matrices cannot be used in serial recall due to the difficulty of recalling them without visual support. Second, the dot task is not subject to the use of verbal strategies, contrarily to Corsi blocks in which verbal re-coding is likely to arise because the location of the TBR objects is fixed and remains visible throughout the presentation (see Berch, Krikorian, & Huha, 1998; Postma & De Hann, 1996). In order to study the processing of spatial information with a serial recall procedure, spatially distributed dots presented one at the time on the computer screen have been used in previous studies (see Farrand & Jones, 1996; Farrand et al., 2001).

EXPERIMENT 1

The aim of Experiment 1 was to directly compare serial recall and order reconstruction tasks. Serial recall required the participants to recall both item and order information whereas in order reconstruction, memory for item information was minimal since items were provided to the participants during recall. In both tasks, series of items were presented sequentially to the participants. In serial recall the participants had to recall

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[1] Since there seems to be no *a priori* LTM representation for dot locations, a good verbal analogue could have been non words. However, a pilot study showed floor effects for the recall of non words. Therefore, the verbal stimuli consisted of low frequency words.

the items in their order of presentation. Different items were presented in each sequence so that the participants had to memorise which items were presented as well as their order for every trial. In order reconstruction the TBR items all reappeared simultaneously for recall and the participants had to select them in their order of presentation. In this task, a closed pool of seven items was used so that the participants could become familiar with the set of items and need only to memorize their order. Experiment 1 also provided a first comparison between the verbal and the spatial domains within the same experiment.

METHOD

Participants. Twenty students from Université Laval participated in the experiment in exchange for a small honorarium. All reported normal or corrected-to-normal vision.

Apparatus and Materials. The experiment was controlled by a PC computer using E-Prime, with a resolution of 640 x 480 pixels. The verbal stimuli were sequences of seven French one-syllable words ranging form 1 to 19 per million (mean = 4.9) according to Baudot's (1992) frequency norms. They were presented visually on the computer screen in the middle of a white window of 450 x 400 pixels, in black capital letters. In verbal serial recall, 154 words were quasi-randomly distributed in 22 sequences of seven words. In verbal reconstruction, all sequences were constructed from the random order of the same seven words. To make sure that participants did not memorize only the first letter of each word, two words began with the same letter (but with different phonology).

The spatial stimuli were sequences of seven black dots of 34 pixels in diameter, presented at different locations within a white window of 450 x 400 pixels. Within a sequence, all seven dots were separated by at least 100 pixels. In the spatial serial recall task, the dots' coordinates were determined randomly for each sequence. In the spatial reconstruction task, the sequences were constructed from random orderings of the same seven dot locations.

Design. There were three repeated-measures factors: Task (2 levels; reconstruction, serial recall), Domain (2 levels; verbal, spatial), and Serial position (7 levels; 1 to 7). Task and Domain were blocked (verbal reconstruction, spatial reconstruction, verbal serial recall, spatial serial recall) and the order of the four conditions was counterbalanced across subjects. There were 20 trials in each condition that were presented in a different random order for each participant.

Procedure. Seven stimuli were presented successively at a rate of one item per second (500 ms on/ 500 ms off). Following presentation, the participants had to recall the stimuli. In spatial reconstruction, all dots reappeared in their original location, whereas in verbal reconstruction, all words reappeared horizontally in alphabetical order. The participants had to click on the stimuli in the order in which they had been presented. Each item turned to green once selected. No omissions were allowed. In spatial serial recall a question mark appeared at the right of the blank window. The participants had to reproduce the sequence by clicking in the window. If the participants did not know an answer, they were required to click on the question mark. In verbal serial recall, participants were prompted by visual instruction to recall. They were required to write down the words, from left to right, in the order in which they had been presented. If the participants did not know an answer, they were instructed to write an “X”. Before the beginning of the experimental trials, two trials per condition were undertaken with the experimenter present to ensure that the participants had understood all of the instructions. The experimental session lasted approximately 40 min.

RESULTS AND DISCUSSION

In spatial serial recall, the acceptance area for a response to the location of each dot to be considered correct was determined according to the coordinates of the dots’ locations. Over all the trials, the shortest distance separating two dots in the same sequence was halved. This value, 50 pixels, was used as the radius for the acceptance area around each dot so that there was no overlap between the acceptance areas for any two dots of the same sequence. For example, a response was considered as correct if the mouse-click fell 50 pixels or less from the correct dot location. All errors examined in the present study are summarized in Table 2. The 2 (Task) x 2 (Domain) x 7 (Serial position) repeated-measures ANOVAs and simple main effects are reported in Appendix A.

Table 2

Illustration of the different types of errors (bold) and of the possible responses following a transposition (underlined) given the hypothetical list 1234567. 0 means that no response was given and 9 refers to an item not presented in the sequence.

Type of error	Recalled sequence	The recalled item is:
Omission	143**0**967	Absent (No item recalled)
Intrusion	1430**9**67	An item not presented in the sequence
Transposition	1**4**30967	An item presented in a different serial position in the TBR list
T1 transposition	12**4**3567	The item presented one serial position later in the TBR list
Followed by a fill-in	12**4**3567	The earliest item in the list that has not yet been recalled
Followed by an associate	12**4**5067	The item following the recalled item in the TBR list
T2+ Transposition	123**6**457	The item presented two or more serial positions later in the TBR list
Followed by a fill-in	123**6**457	The earliest item in the list that has not yet been recalled
Followed by an associate	123**6**750	The item following the recalled item in the TBR list
Followed by a correct response	123**6**507	The correct response

Comparison between serial recall and order reconstruction. The distribution of errors in all conditions exhibited primacy and slight recency effects (see Figure 1). The presence of a significant interaction between Task and Serial position suggests that recency was greater for order reconstruction compared to serial recall. The same difference was also

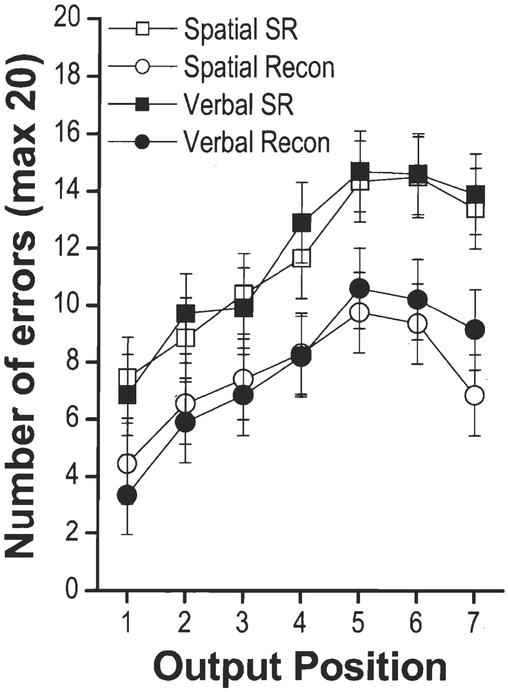

Figure 1. Number of errors as a function of serial position in verbal and spatial serial recall and reconstruction in Experiment 1. Error bars represent 95% confidence intervals

obtained with the pattern of transpositions (see Figure 2). A transposition was scored when an item was recalled in a different serial position than that in which it had been presented. Indeed, the interaction between Task and Serial position was again significant. This interaction was probably due to the fact that in serial recall the distribution of transpositions was relatively flat and symmetrical whereas transpositions increased from serial position 1 to 5 and sharply decreased thereafter in order reconstruction. A possible explanation is that when participants do not remember an item in order reconstruction, they must guess and thus produce a transposition. In line with this idea, the pattern of transpositions in order reconstruction was very similar to that of omissions in serial recall, and the proportion of transpositions[2] was much higher in order reconstruction than in serial recall (Figure 3). The

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[2] We first computed the number of transpositions committed in each condition (see Figure 2). Computing the number of transpositions is useful in order to examine their distribution, but it may be inappropriate in order to compare the different conditions (see Murdock & Vom Saal, 1967; Saint-Aubin & Poirier, 1999). Since a transposition cannot be computed unless an item is recalled, a condition in which few items are output is more likely to yield a small number of transpositions than a condition in which most of the items are output. A better comparison between conditions is achieved by dividing the number of transpositions by the number of items recalled (in the correct order or not). This measure is referred to as the *proportion* of transpositions.

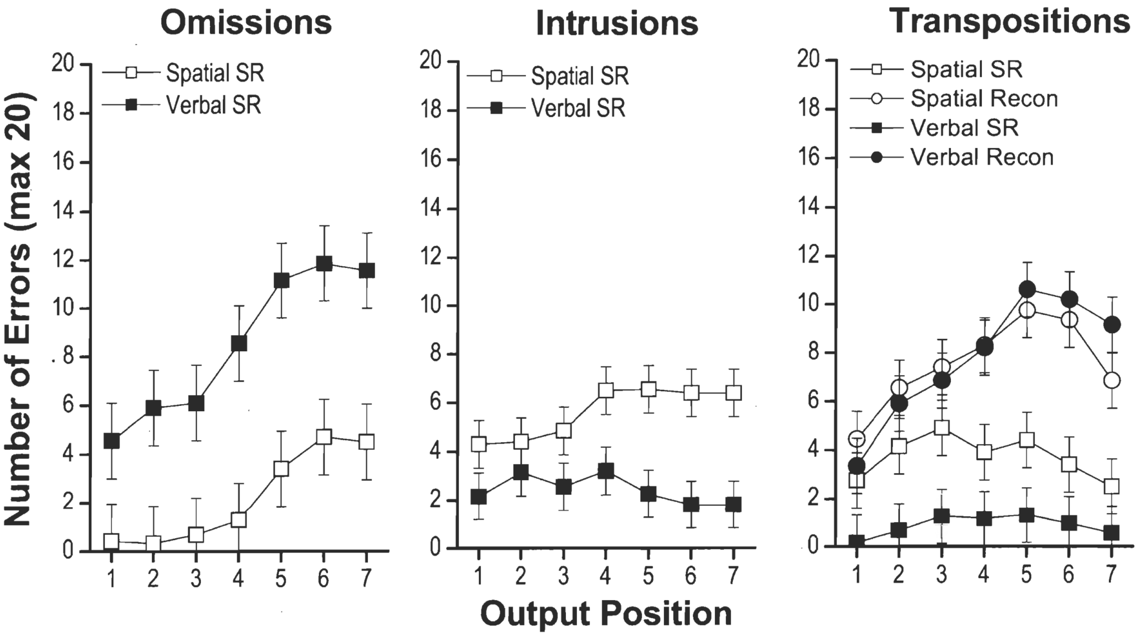

Figure 2. Number of omissions (left) and intrusions (middle) as a function of serial position in verbal and spatial serial recall, and number of transpositions (right) as a function of serial position in verbal and spatial serial recall and reconstruction in Experiment 1. Error bars represent 95% confidence intervals.

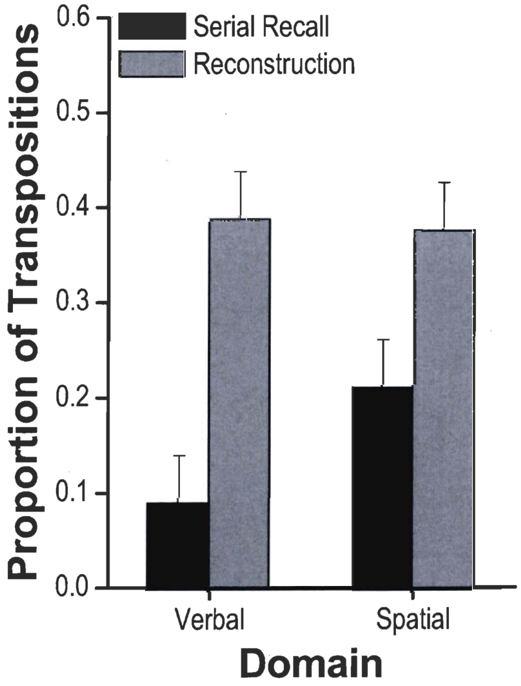

Figure 3. Proportion of transpositions in verbal and spatial serial recall and reconstruction in Experiment 1. Error bars represent 95% confidence intervals.

latter finding was confirmed by a 2 (Task) x 2 (Domain) repeated-measures ANOVA carried out on the proportion of transpositions. The analysis showed that the main effect of Domain was not significant, $F(1, 19) = 3.96$, $MSE = 0.01$, but that the interaction between Task and Domain was significant, $F(1, 19) = 12.36$, $MSE = 0.01$. Importantly, the main effect of Task was significant, $F(1, 19) = 101.95$, $MSE = 0.01$. These results suggest that order reconstruction is not so much a pure test of order memory (e.g., Neath, 1997).

Comparison between the spatial and verbal domains. The distribution of errors according to the strict serial recall criterion was very much the same for the spatial and the verbal tasks (Figure 1). When no item was recalled for a given serial position, as indexed by a written "X" in verbal serial recall and a click on the question mark in spatial serial recall, an omission was calculated. Figure 2 indicates that the distribution of omissions was similar across spatial and verbal tasks: Omissions increased as a function of serial position. Also, for both verbal and spatial TBR stimuli, the distribution of transpositions was bow-shaped in reconstruction as well as in serial recall. The similarities between the two domains suggest that the processing of verbal and that of spatial information is functionally equivalent.

The pattern of responses following a transposition was also analysed. The first type of transpositions consisted of an item recalled one serial position before that in which it had been presented (*t1* transposition). The response following the transposition was scored as a *fill-in* when it consisted of the earliest item in the list that had not yet been recalled, as an *associate* if this item was the one following the recalled item in the TBR list, or as *other*. The second type of transpositions consisted of an item recalled more than one serial position before that in which it had been presented (*t2+* transposition). The following response could be scored as a fill-in, as an associate, or as other. It could also be recalled correctly and scored as *correct*. Only the response following the first transposition produced in the recalled sequence was analysed. Because of the low number of observations in serial recall (20 *t1* or *t2* transpositions in the verbal and 114 in the spatial task), only the data from the reconstruction tasks are reported throughout this chapter.

Because some participants committed very few transpositions, the overall number of each type of responses, not averaged across participants is reported in Table 3. The pattern of responses following a *t1* transposition was very similar in the two conditions, with fill-ins being 2.8 and 3.6 times greater than associates in verbal and spatial reconstruction (see Henson, 1996; Surprenant et al., 2005). The pattern of responses following a *t2* transposition however, differed between the verbal and spatial tasks. In verbal reconstruction, the pattern is similar to that observed by Henson (1996), with correct responses being 1.7 times more numerous than fill-ins, and 5.4 times superior to associates.

Table 3

Number of t1 and t2 transpositions as well as the proportion of fill-ins, associates and correct responses following t1 and t2+ transpositions in the verbal and spatial reconstruction tasks of Experiments 1 and 2.

				Following Response			
First Error	**Exp.**		**Nb of errors**	**Fill-In**	**Correct Resp.**	**Associ-ate**	**Other**
T1	1	Verbal	100	0.65	-	0.23	0.12
		Spatial	151	0.72	-	0.20	0.09
	2	Verbal	100	0.39	0.01	0.19	0.41
		Verbal (AS)	84	0.35	0.00	0.12	0.54
		Spatial	180	0.62	0.00	0.21	0.17
		Spatial (AS)	137	0.57	0.00	0.22	0.21
	2	Verbal	99	0.35	0.01	0.18	0.45
		Verbal (Tap)	93	0.41	0.01	0.18	0.40
		Spatial	200	0.62	0.00	0.23	0.16
		Spatial (Tap)	142	0.56	0.00	0.18	0.26
T2+	1	Verbal	175	0.26	0.43	0.08	0.22
		Spatial	115	0.40	0.43	0.05	0.11
	2	Verbal	132	0.20	0.36	0.08	0.36
		Verbal (AS)	162	0.29	0.20	0.06	0.44
		Spatial	115	0.37	0.41	0.05	0.17
		Spatial (AS)	118	0.39	0.31	0.08	0.22
	2	Verbal	116	0.19	0.43	0.16	0.22
		Verbal (Tap)	142	0.25	0.37	0.06	0.32
		Spatial	116	0.37	0.28	0.04	0.30
		Spatial (Tap)	146	0.26	0.32	0.05	0.36

In spatial reconstruction however, correct responses were only 1.1 times more numerous than fill-ins, and 8.3 times superior to associates.

When a word not in the just-presented list was recalled in verbal serial recall and when a mouse click fell outside the seven acceptance areas in spatial serial recall, an intrusion was calculated. As shown in Figure 2, intrusions tended to decrease as a function of serial position in verbal serial recall, but to increase in spatial serial recall. Although this difference suggests that different mechanisms underlie the production of intrusions in the verbal and spatial tasks, it is possible that this difference is task-related rather than the manifestation of different memory mechanisms. In spatial serial recall, participants had to *select* a location on the screen in order to produce a response, whereas an item had to be *generated* in verbal serial recall. Therefore, intrusions were more likely to be produced in spatial serial recall as any selection of an irrelevant location – that is, anywhere on the screen not covered by the TBR locations and their surrounding zone of acceptance – had to be counted as an intrusion. As much as verbal and spatial order reconstruction tasks were equated for processing order information and provided similar patterns of errors, Experiment 1 has highlighted a key limitation in equating spatial and verbal serial recall tasks: Equation in terms of item memory is limited by the response production requirements. In order to fully equate the verbal and spatial memory tasks, we employed a variant of order reconstruction in Experiment 2.

EXPERIMENT 2

Several studies have examined the effect of verbal and spatial interference on the short-term retention of verbal and spatial information and observed a dissociation based on stimulus domain (see, e.g., Farmer et al., 1986). The objective of Experiment 2 was to investigate the effect of articulatory suppression and spatial tapping on the distribution of errors in the verbal and spatial memory tasks. As the effect of articulatory suppression with verbal memory, tapping is reputed to interfere with the processing of spatial information (see, e.g., Andrade, Kemps, Werniers, May, & Szmalec, 2002). In order to equate the verbal and spatial memory tasks as much as possible, we used a variant of the order reconstruction task. Series of seven words or dots randomly selected from the same pool of nine items were presented to the participants. After presentation, all nine items appeared simultaneously on the screen and the participant had to select the correct items in the correct order. In both verbal and spatial reconstruction, an intrusion was committed when one item not presented in the TBR list was selected. Omissions were allowed by clicking on a question mark at the right of the window. This variant of spatial and verbal order reconstruction was used in combination with articulatory suppression and tapping.

METHOD

Participants. Fifty two students[3] from Université Laval participated in the experiment in exchange for a small honorarium. All reported normal or corrected-to-normal vision.

Apparatus and Materials. The apparatus and materials were as in the order reconstruction conditions of Experiment 1 except that the stimuli consisted the same nine dot locations in spatial reconstruction and nine low frequency words in verbal reconstruction. In each sequence, seven items were randomly selected from that pool of nine items. In the tapping condition, a device consisting of four wooden plates arranged in a square was used. The wooden plates were 5 cm x 5 cm and were all separated by 4 cm. A wooden panel hid the plates from the participants' view. The participants' hand was filmed and their movements were recorded simultaneously with what was presented on the screen, using the program *Morae 1.1*. The participants were filmed during the whole experimental session.

Design. One group performed the articulatory suppression task and one group performed the tapping task. In each group, there were three repeated-measures factors: Domain (2 levels; spatial, verbal), Suppression (2 levels; control, suppression) and Serial position (7 levels; 1 to 7). Domain and Suppression were blocked (verbal control, verbal suppression, spatial control, spatial suppression) and the order of the four conditions was counterbalanced across participants. There were 20 trials in each condition that were presented in a different random order for each participant.

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[3] There were 24 participants in the articulatory suppression group and 28 participants in the tapping group. The articulatory suppression condition and the spatial tapping condition were conducted as two separate experiments. For that reason, they will be examined with separate analysis.

Procedure. Before the beginning of the experimental session, the participants were given a training session with the suppression task. In the articulatory suppression group, the training session consisted of presenting repeatedly the letters from A to D sequentially on the screen at the rate of one letter every 500 ms (500 ms on/0 ms off). The participants were required to repeat the letters at the same rate at which they were presented on the screen. In order that participants became accustomed to the rate of presentation without the visual support, variable intervals in which the screen remained blank were presented throughout the training session. The participants were instructed to continue saying the letters at the same rate during these intervals. In the tapping group, the training session consisted of presenting a 250 Hz tone through headphones at the rate of one every 500 ms (200 ms on/300 ms off). Participants were required to touch the plates counter clockwise with their dominant hand, at the same rate at which they heard the sounds. The training session lasted approximately 2 min.

In the articulatory suppression group, at the beginning of each trial, the letters "A, B, C, D, A" were presented sequentially on the screen at a rate of one letter every 500 ms, in order to set the pace for the suppression task. In the suppression condition, the participants were instructed to read these letters aloud and to continue the suppression at the same rate during item presentation until recall (even though the letters were not presented during item presentation). In the control condition, they were told to ignore those letters. Articulatory suppression was recorded during the experiment and verified using the *Sound Forge 1.0.* software. In the tapping group, before each trial, five sounds were presented sequentially through the headphones at a rate of one every 500 ms in order to set the pace. In the suppression conditions, the participants were instructed to begin tapping when they heard the first sound and to continue at the same rate until recall (even though no sound was presented during item presentation). In the control condition, they were told to ignore the sounds.

The first to-be remembered stimulus appeared 750 ms after the last A or sound. Once the sequence of seven items had been presented, nine items appeared on the screen (spatially distributed dots in the spatial task and words presented in alphabetical order in a row in the verbal task). The participants had to select the seven items that had appeared in the sequence, in the same order as they had been presented. Each time an item was selected, a thermometer at the right of the window indicated how many items had been recalled. In this experiment, an item did not turn to green once selected. When the participants did not know an answer, they were instructed to click on a question mark.

RESULTS AND DISCUSSION

Five trials out of 960 in the articulatory suppression group and thirty-one trials out of 1120 in the tapping group were removed from the analyses due to errors committed in the suppression task (e.g., when participants changed pace, failed to repeat the letter-sequence fluently, or touched the blocks in the wrong order). All 2 (Task) x 2 (Domain) x 7 (Serial position) repeated-measures ANOVAs are reported in Appendix B.

Comparison between the spatial and verbal domains. As shown in Figure 4, serial position curves exhibited primacy and recency effects in all conditions. In both groups, the

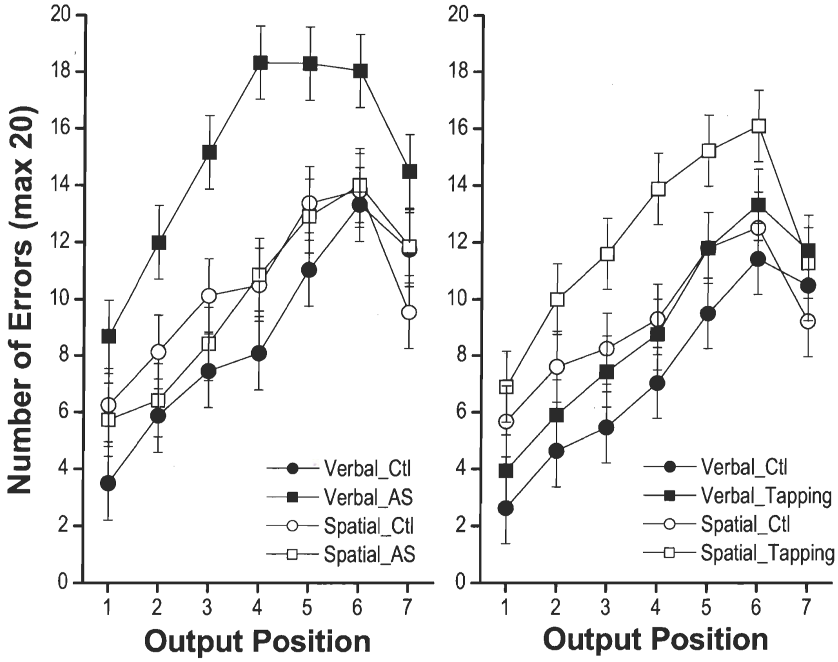

Figure 4. Number of errors as a function of serial position in verbal and spatial reconstruction for the control and suppression conditions in the articulatory suppression (left) and tapping groups (right) of Experiment 2. Error bars represent 95% confidence intervals.

distribution of errors was similar across domains, though the mere number of errors in spatial reconstruction was higher than that in verbal reconstruction. The distributions of omissions, intrusions and transpositions were equivalent across the spatial and verbal memory tasks: omissions and intrusions increased as a function of serial position and transpositions were predominant for the middle serial positions (see Figure 5). In the context of memory research and establishing functional equivalence in processing TBR information, the present finding reinforces the importance of equating verbal and spatial memory tasks on all aspects but the TBR material (see also Ward et al., 2005). Moreover, the results of the present experiment suggest that the processing of spatial and that of verbal information is functionally equivalent.

As in Experiment 1, the pattern of responses following a *t1* transposition was similar across domains. The ratios were very similar in the articulatory suppression and tapping groups. Therefore, the following ratios include data for both groups. The number of fill-ins was 2.0 and 2.8 times superior to the number of associates in the verbal control and spatial control conditions (Table 3). The pattern of responses following a *t2* transposition differed across domains however. Correct responses outnumbered fill-ins by 2 times in the verbal control condition and fill-ins outnumbered correct responses by 1.1 times in the spatial control condition.

The main finding in support of modularity was the selective interference of articulatory suppression on verbal memory and that of tapping on spatial memory. Indeed, in line with previous studies (see e.g., Farmer et al., 1986), articulatory suppression increased the number of errors in verbal reconstruction, but had no effect on the number of errors in spatial reconstruction (Figure 4). Conversely, tapping increased the number of errors in spatial reconstruction, and to a lesser extent, in verbal reconstruction.

The locus of interference. Both articulatory suppression and tapping increased the number of omissions (Figure 5) and the proportion of transpositions (Figure 6). The latter finding was confirmed by 2 (Domain) x 2 (Suppression) repeated-measures ANOVAs carried out on the proportion of transpositions. In the articulatory suppression group, the main effect of Domain was significant, $F(1, 23) = 4.12$, $MSE = 0.01$, as well as the interaction between Domain and Suppression, $F(1, 23) = 22.45$, $MSE = 0.01$. The effect of

Suppression was not significant ($F < 1$). Simple main effects confirmed that articulatory suppression increased the proportion of transpositions in verbal reconstruction, $F(1, 23) =$

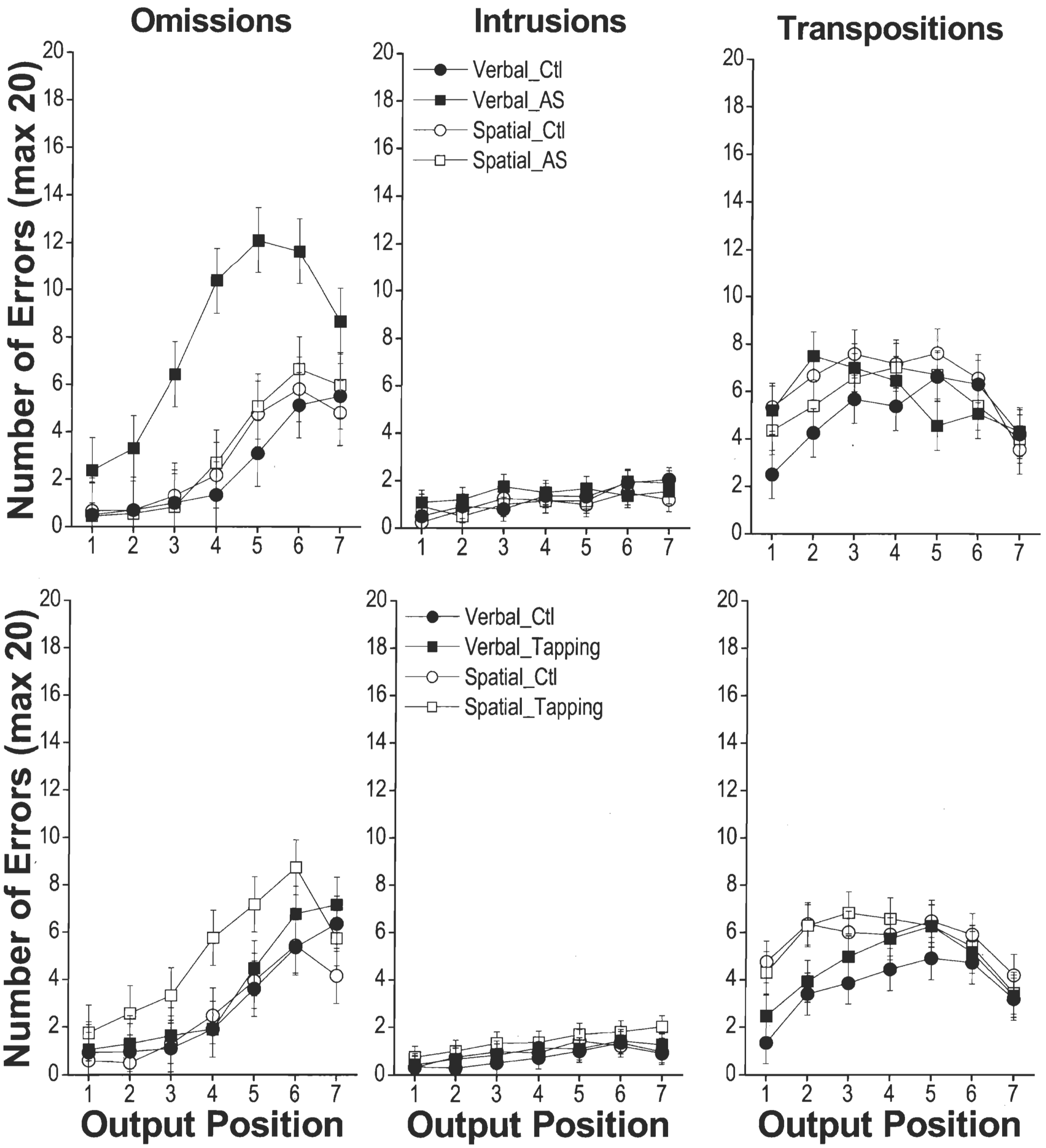

Figure 5. Number of omissions (left), intrusions (middle), and transpositions (right) as a function of serial position in verbal and spatial reconstruction for the control and suppression conditions in the articulatory suppression (top) and tapping groups (bottom) of Experiment 2. Error bars represent 95% confidence intervals.

13.05, *MSE* = 0.02, and decreased the proportion of transpositions in spatial reconstruction, *F*(1, 23) = 4.45, *MSE* = 0.01. In the tapping group, the main effects of Domain, *F*(1, 27) = 4.07, *MSE* = 0.01, and of Suppression, *F*(1, 27) = 20.39, *MSE* = 0.01, were significant. The interaction between Domain and Suppression was not significant ($F < 1$), suggesting that the proportion of transpositions increased under tapping, no matter the domain of information. Tapping also increased the number of intrusions in both verbal and spatial

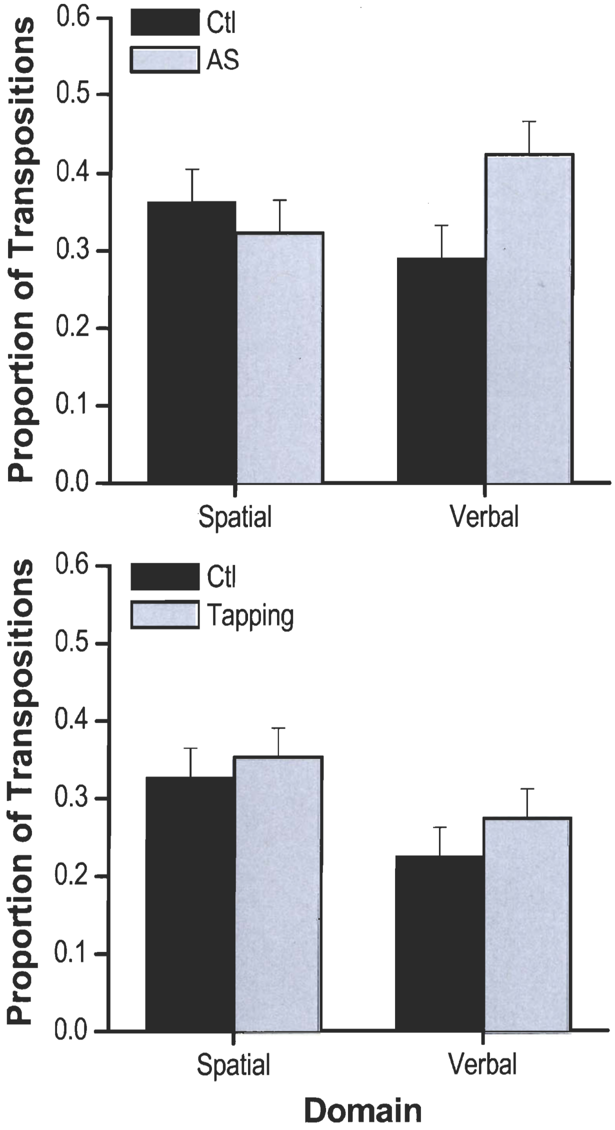

Figure 6. Proportion of transpositions in verbal and spatial reconstruction for the control and suppression conditions in the articulatory suppression (top) and tapping groups (bottom) of Experiment 2. Error bars represent 95% confidence intervals.

reconstruction (Figure 5). Finally, suppression affected the ratio between fill-ins and correct responses following a *t2* transposition in the verbal condition (Table 3). In the articulatory suppression group, correct responses outnumbered fill-ins by 1.8 times in the verbal control condition, and fill-ins were 1.5 time superior to correct responses under articulatory suppression. In the tapping group, correct responses outnumbered fill-ins by 2.3 times in the verbal control condition, and by only 1.5 times in the suppression condition.

GENERAL DISCUSSION

The goal of the present series of experiments was to revisit the apparently contradictory lines of evidence pertaining to modularity and functional equivalence between the verbal and spatial domains by taking great care to equate tasks across domains and examining the patterns of errors. In all experiments, the distribution of omissions and transpositions were comparable between the two domains. Moreover, when response production was equated between tasks, the distribution of intrusions was also similar in the verbal and spatial tasks. Experiment 2 revealed a double dissociation between the verbal and spatial domains: articulatory suppression interfered more with the verbal tasks than with the spatial tasks, and tapping impaired the spatial tasks more than the verbal tasks (see, e.g., Meiser & Klauer, 1999). Both articulatory suppression and tapping affected mostly the number of omissions and the proportion of transpositions.

EVIDENCE FOR FUNCTIONAL EQUIVALENCE

According to a number of researchers (e.g., Brown et al, 2007; Cowan, 1993; Jones et al., 2006; Jones et al., 1996), there is no need to postulate separate memory systems for the processing of verbal and spatial information. In support of functional equivalence, serial position curves in the verbal and spatial domains were very similar, with marked primacy and small recency effects as it is usually reported in the visual modality (see, e.g., Battacchi, Pelamatti, & Umilta, 1990; Tremblay, Parmentier, Guérard, Nicholls, & Jones, 2006). The detailed analysis of errors showed similar bow-shaped distributions of transpositions regardless of stimulus domain. The distribution of omissions was also found to be similar in the verbal and spatial tasks, that is, they generally increased with serial position. Experiment 1 indicated that intrusions were distributed differently between verbal and spatial serial recall. When the production of responses was equated in Experiment 2 however, they increased slightly as a function of serial position in both domains. The difference between Experiments 1 and 2 emphasizes the importance of having equivalent tasks when comparing performance across domains. Further evidence of functional equivalence come from the locus of interference, which was the same whether articulatory suppression or spatial tapping was carried out: suppression, though, domain specific, had an impact on the number of omissions and of transpositions. This could have occurred if, by preventing rehearsal, suppression lowered the level of activation (see Burgess & Hitch, 1999; Henson, 1998; Page & Norris, 1998), or increased item similarity (Brown et al., 2007).

EVIDENCE FOR MODULARITY

A model that is often evoked to account for the dissociation between the verbal and spatial domains is the Working Memory Model (Baddeley, 1986; Baddeley & Hitch, 1974) which posits the existence of two specialised subsystems responsible for the processing of verbal and spatial information, namely the phonological loop and the visuo-spatial sketchpad. In such a model, interference arises when two tasks rely on the same subsystem. For example, when the participants utter irrelevant items during a verbal memory task, their recall performance is poorer compared to a silent condition because both tasks rely on the phonological loop (Larsen & Baddeley, 2003; Meiser & Klauer, 1999; Murray, 1968).

While our analysis of errors promotes functional equivalence, the pattern of interference observed in Experiment 2 provides evidence for modularity by revealing a double dissociation between the verbal and the spatial domains (see, e.g., Farmer et al., 1986; Logie et al., 1990; Meiser & Klauer, 1999; Salway & Logie, 1995). Although Experiment 2 showed an effect of tapping on verbal reconstruction, the size of the effect was less than that observed on spatial reconstruction. Another finding in support of a modular account is the pattern of fill-ins. In verbal reconstruction, the production of a transposition was generally followed by the correct response. When the correct response had already been recalled however, the earliest item of the TBR list that had not yet been recalled (a fill-in) tended to be output. This pattern is consistent with the results reported by Henson (1998). In spatial reconstruction however, the response following a *t2* transposition was equally likely to be a fill-in and the correct response. One possible explanation for this pattern is that order information is less predominant in memory for spatial information than in the verbal domain (i.e. weaker item-context associations; Brown et al., 2000; see Nairne & Dutta, 1992). In line with this hypothesis, we observed that transpositions were more numerous in the spatial tasks than in the verbal tasks, even when all other types of errors were equated in Experiment 2.

RECONCILING MODULARITY AND FUNCTIONAL EQUIVALENCE

One way to reconcile modularity and functional equivalence is to retain the modularity approach and to suppose that the visuo-spatial sketchpad operates in a comparable fashion to the phonological loop (see Logie, 1995), as indicated by the similar patterns of errors observed across the verbal and spatial domains. However, the assumption that the verbal and spatial components are equivalent obviates the need for independent modules, given that a non-modular account can be supplied in order to account for the observed selective interference. Indeed, there are two non-modular views that provide an explanation of the selective interference reported in the present study. A first alternative explanation, refers to the concept of similarity. This concept is fundamental in cognition (Crowder, 1979; Duncan & Humphreys 1989) and at the basis of distinctiveness models of STM (Brown et al., 2000, 2007; Nairne, 1990; Neath, 1999). Although the same mechanisms would be responsible for the processing of spatial and verbal information – and yield equivalent patterns of errors in both domains – selective interference would occur because of the overlap between the TBR and interfering stimuli. One such model is the Interference model developed by Oberauer and Kliegl (2006). In this model, the presentation of a TBR item activates a corresponding set of features in memory. When two items held in memory share similar features they compete so that one of the representations loses features through feature overwriting (see also Nairne, 1990; Neath, 1999). This model was successful in accounting for performance in spatial and verbal STM using the same basic principles and could therefore account for the similar patterns of errors reported in this experiment. Moreover, since the level of feature overwriting is proportional to the number of features shared between two items, the model can reproduce a typical double dissociation. For example, tapping would interfere more with the processing of spatial than that of verbal information because the spatial component of the interfering task is more similar to the TBR spatial locations than to the TBR words. Conversely, articulatory suppression would be more disruptive for verbal than for spatial memory because the irrelevant letters pronounced by a participant share more features with the TBR words than with the TBR spatial locations.

Another candidate for reconciling the apparent contradiction between modularity and functional equivalence is the gestural-perception framework (see Jones et al., 2006; Jones, Macken, & Nicholls, 2004), based on the concept of selection for action put forward by Neumann (1987). Within this framework, the memory processes are closely related to the perceptual organisation of the stimuli and to the gestural components (e.g., speech processes) associated with the execution of a memory – or interference – task. Selective interference arises when the STM and interference tasks rely on similar skills: articulatory suppression would prevent the use of language production as a skill to support verbal rehearsal (see Jones et al., 2004) whereas spatial tapping would interfere with motor actions such as oculomotor movements as a skill to support the retention of visuo-spatial information (see Tremblay, Saint-Aubin, & Jalbert, 2006). Since the same processes are responsible for the processing of all types of information, such an account predicts that the patterns of errors should be equivalent between the spatial and verbal domains. Moreover, selective interference would occur based on the assumption that two tasks using the same types of stimuli will require the use of the same gestural skills.

CONCLUSIONS

The present series of experiments revisited the evidence for modularity and functional equivalence in STM by systematically examining the contribution of the different types of errors to the presence of similarities and dissociations across verbal and spatial domains. The analysis of errors indicated that a good model of STM should explain how transpositions and omissions are selectively affected by interference in addition to being able to account for the processing of spatial information without any additional assumption.

Indeed, most quantitative models are very effective in accounting for the various verbal STM phenomena and there is no reason why they should not be extended to account for the processing of spatial information. What is now needed is an exhaustive computational comparison that falls beyond the scope of our work. The present study also reinforced the importance of equating tasks in every respect and showed that the requirements associated with the recall of item information may have been confounded with domain when comparing verbal serial recall and spatial reconstruction.

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APPENDIX A

Analyses of Variance and Simple Main effects for the Errors Scored as a Function of the Strict Serial Recall Criterion, Omissions, Intrusions and Transpositions in Experiment 1.

Source	*df*	*F*	*MSE*
	Strict serial recall		
Task (T)	1, 19	127.94†	17.67
Domain (D)	1, 19	0.13	70.54
Serial position (SP)	6, 114	50.58†	16.76
T × D	1, 19	0.01	16.55
T × SP	6, 114	3.29*	13.50
D × SP	6, 114	1.38	19.73
T × D × SP	6, 114	1.28	12.05
	Omissions		
Domain	1, 19	92.32†	30.58
Serial position	6, 114	26.99†	22.19
D × SP	6, 114	1.32	37.78
	Intrusions		
Domain	1, 19	32.11†	22.52
Serial position	6, 114	2.90*	3.78
D × SP	6, 114	5.54†	3.27
	Transpositions		
Task	1, 19	111.20†	36.04
Domain	1, 19	6.63*	36.48
Serial position	6, 114	25.68†	7.87
T × D	1, 19	14.90†	22.36
T × SP	6, 114	22.84†	5.48
D × SP	6, 114	4.09†	3.27
T × D × SP	6, 114	1.40	2.92
Simple main effects (Serial recall)			
Domain	1, 19	42.55†	13.42
Serial position	6, 114	6.30†	4.11
D × SP	6, 114	1.40	4.15

$^*p < .05$. †$p < .01$.

APPENDIX B

Analyses of Variance and Simple Main effects for the Errors Scored as a Function of the Strict Serial Recall Criterion, Omissions, Intrusions and Transpositions in the Articulatory Suppression and Tapping Groups of Experiment 2.

Articulatory Suppression

		Serial recall		**Omissions**		**Intrusions**		**Transpositions**	
Source	*df*	*F*	*MSE*	*F*	*MSE*	*F*	*MSE*	*F*	*MSE*
Domain (D)	1, 23	14.00†	35.46	33.95†	22.30	3.45	2.65	3.88	17.56
Suppression (S)	1, 23	72.21†	21.38	80.62†	16.68	2.63	2.45	0.00	22.53
Serial position (SP)	6, 138	68.50†	33.96	26.72†	83.73	7.01†	3.54	16.09†	11.19
D × S	1, 23	52.27†	33.92	52.16†	20.77	0.03	1.55	4.43*	20.02
D × SP	6, 138	2.29	11.22	2.30	20.44	0.45	3.06	3.23*	6.81
S × SP	6, 138	6.20†	4.56	11.90†	9.71	0.80	1.64	4.50†	7.60
D × S × SP	6, 138	9.19†	11.91	7.56†	15.06	3.92†	1.09	7.99†	3.50
Simple main effects (Verbal reconstruction)									
Suppression	1, 23	71.24†	46.50	72.87†	33.23	0.95	2.82	1.35	33.26
Serial position	6, 138	67.56†	17.26	26.81†	41.09	2.87*	3.13	7.16†	10.78
S × SP	6, 138	10.12†	10.92	12.73†	18.69	2.39*	1.50	9.40†	8.63
Simple main effects (Spatial reconstruction)									
Suppression	1, 23	0.45	8.80	1.67	4.23	3.23	1.18	4.70*	9.28
Serial position	6, 138	32.34†	28.85	15.81†	63.76	5.28†	2.55	17.16†	7.14
S × SP	6, 138	4.92†	7.21	1.30	9.58	1.62	1.76	1.30	3.69

Tapping

		Serial recall		**Omissions**		**Intrusions**		**Transpositions**	
Source	*df*	*F*	*MSE*	*F*	*MSE*	*F*	*MSE*	*F*	*MSE*
Domain (D)	1, 27	16.28†	76.50	1.53	51.24	5.78*	3.39	19.57†	22.44
Suppression (S)	1, 27	44.24†	23.67	24.35†	17.58	9.16†	2.85	2.00	15.19
Serial position (SP)	6, 162	70.20†	38.22	36.92†	47.90	8.12†	2.71	19.47†	12.90
D × S	1, 27	5.81*	13.74	10.57†	14.95	1.53	2.07	5.92*	7.08
D × SP	6, 162	7.61†	21.43	6.07†	18.81	0.47	2.59	4.36†	8.66
S × SP	6, 162	3.06*	7.88	2.38	9.78	0.73	1.85	2.31	4.36
D × S × SP	6, 162	1.37	6.87	1.27	9.63	0.59	1.93	0.43	5.91
Simple main effects (Verbal reconstruction)									
Suppression	1, 27	13.52†	20.30	5.64*	5.84	-	-	7.00*	1.47
Serial position	6, 162	44.07†	39.00	24.01†	50.18	-	-	-	-
S × SP	6, 162	0.54	9.41	1.02	6.74	-	-	-	-
Simple main effects (Spatial reconstruction)									
Suppression	1, 27	49.85†	17.10	20.72†	26.69	-	-	0.04	1.72
Serial position	6, 162	46.56†	21.76	31.01†	21.25	-	-	-	-
S × SP	6, 162	4.17†	4.25	2.39	13.18	-	-	-	-

*$p < .05$. † $p < .01$.

CHAPITRE III

LE TRAITEMENT DE L'INFORMATION SPATIALE EN MÉMOIRE À COURT TERME : L'EFFET DE LONGUEUR DU SENTIER ET LE MOUVEMENT OCULAIRE

RÉSUMÉ

Lors d'une tâche de mémoire spatiale, le rappel diminue en fonction de la distance qui sépare les localisations successives à mémoriser. Cet effet, appelé l'effet de longueur des sentiers (Parmentier, Elford, & Maybery, 2005), est étudié afin de déterminer si l'efficacité avec laquelle les yeux sont déplacés entre les localisations affecte la rétention de l'information spatiale. Le mouvement oculaire est mesuré lors d'une tâche de mémoire où les participants doivent rappeler l'ordre dans lequel des séquences de localisations sont présentées à l'écran. Dans l'Expérience 1, le mouvement oculaire est bloqué par l'utilisation d'une tâche de suppression oculaire pendant laquelle les participants doivent bouger les yeux sans arrêt entre deux localisations. La suppression oculaire abolit l'effet de longueur des sentiers, qu'elle soit effectuée à l'encodage ou pendant un intervalle de rétention. Dans l'expérience 2, une tâche de suppression articulatoire est combinée avec la tâche de mémoire. Les résultats montrent que la suppression articulatoire affecte la performance, mais n'interagit pas avec l'effet de longueur des sentiers. Les résultats suggèrent que l'autorépétition, et plus précisément le mouvement oculaire, joue un rôle clé lors de la rétention de l'information spatiale.

THE PROCESSING OF SPATIAL INFORMATION IN SHORT-TERM MEMORY: INSIGHTS FROM EYE TRACKING THE PATH LENGTH EFFECT

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ABSTRACT

Serial memory for spatial locations increases as the distance between successive stimuli locations decreases. This effect, known as the path length effect (Parmentier, Elford, & Maybery, 2005), was investigated in a systematic manner using eye tracking and interference procedures to explore the mechanisms responsible for the processing of spatial information. In Experiment 1, eye movements were monitored during a spatial serial recall task – in which participants have to remember the location of spatially and temporally separated dots on the screen. In the experimental conditions, eye movements were suppressed by requiring participants to incessantly move their eyes between irrelevant locations. Ocular suppression abolished the path length effect whether eye movements were prevented during item presentation or during a 7-sec retention interval. In Experiment 2, articulatory suppression was combined with spatial serial recall. Although this interfering task impaired performance, it did not alter the path length effect. Our results suggest that rehearsal plays a key role in serial memory for spatial information.

INTRODUCTION

Although memory over the short term has been a concern for over a century, the processing of spatial information has received less attention than its verbal counterpart. Furthermore, most of the work on memory for spatial information has focused on establishing its independence from verbal memory systems (see, e.g., Farmer, Berman, & Fletcher, 1986; Meiser & Klauer, 1999). In more recent years the center of interest has shifted towards the characterization of the mechanisms underlying short-term memory (STM) performance in the spatial domain (Awh & Jonides, 2001; see also Logie, 1995). The aim of the present study is to further the understanding of the mechanisms at play in STM for spatial information by investigating the path length effect – the finding that performance declines as the spatial distance between the successive locations increases (Parmentier, Elford, & Maybery, 2005) – within a paradigm combining the classical serial recall procedure and the analysis of eye movements.

In order to study memory for spatial information, we used the dot task where participants have to reproduce the order in which series of spatially distributed dots were presented on a computer screen (see Jones, Farrand, Stuart, & Morris, 1995). Using the dot task or similar spatial memory tasks such as the Corsi block task, a number of researchers have highlighted limitations in the processing of spatial information by identifying key features of the spatial stimuli that modulate performance in spatial serial recall (e.g., Kemps, 1999, 2001; Parmentier & Andrés, 2006; Parmentier, Andrés, Elford, & Jones, 2006; Parmentier et al., 2005). For example, Kemps (2001) showed that when the first half of the spatial configuration formed by the series of to-be-remembered (TBR) locations was symmetrical to the second half, accuracy was better than when the locations were random. In another study, Parmentier et al. (2005) reported that the number of times the paths connecting two successive locations cross each other during item presentation was negatively related to performance. Such findings suggest that the way spatial information is organized is determinant of subsequent recall. However, it is unclear how memory processes are affected by the features of the spatial TBR stimuli.

The key characteristic examined in the present study is the length of the path connecting the successive dot locations. Parmentier et al. (2005) reported that performance decreased markedly as the distance between consecutive items of a sequence increased. However, the memory processes responsible for the path length effect remain to be elucidated. In the present study, we wish to determine the locus of the path length effect in order to understand further the mechanisms involved in the serial recall of spatial memory representations. Parmentier et al. suggested that path length could affect memory performance in two different ways: path length could either interfere with the memory processes taking place during the encoding of the TBR items or alter the efficiency of rehearsal.

The first hypothesis is that path length affects processes that are active at encoding, that is, during the presentation of the TBR locations. As the distance between two locations increases, the time required to plan and execute a saccade between these locations increases (Abrams, Meyer, & Kornblum, 1989). Accordingly, the time left to process these locations decreases. It is therefore possible that increasing the distance between the memory locations in a spatial STM task decreases recall performance because the amount of time left to process each location is reduced (see, e.g., Saint-Aubin, Tremblay, & Jalbert, 2007).

Another account of the path length effect is that the distance between successive locations modulates the efficiency of spatial rehearsal (see Parmentier et al., 2005). Rehearsal can be viewed as a process that allows refreshing the activation of an item in memory (e.g., see Baddeley, 1986; Logie, 1995) or as a strategy to transform a series of TBR items into a sequence of gestures which facilitates structuring the information and supports recall (see Hughes, Marsh, & Jones, 2008). Although the exact nature of spatial rehearsal is still debated, most researchers agree that it plays a key role in the retention of spatial information. Some have suggested that spatial rehearsal is mediated by attentional shifts (see Awh & Jonides, 1998, 2001; Smyth, 1996), but in the case of serial memory, it has also been associated with eye movements (see Baddeley, 1986; Brockmole & Irwin, 2005; Lawrence, Myerson, & Abrams, 2004; Lawrence, Myerson, Oonk, & Abrams, 2001; Pearson & Sahraie, 2003; Tremblay, Saint-Aubin, & Jalbert, 2006). Baddeley suggested that the planning of eye movements is at basis of spatial rehearsal whereas others see eye movements as an overt manifestation of attentional shifts (e.g., Tremblay et al., 2006). Path length could therefore interact with rehearsal by modulating eye movement efficiency.

The objective of the following experiments was to explore the mechanisms at play during the encoding and rehearsal of spatial information through the study of the path length effect. The procedure used by Parmentier et al. (2005) was employed in the following experiments so that half the TBR sequences consisted of short paths — that is to say that the distance between consecutive dots was short — and the other half consisted of long paths in which the distance between consecutive dots was longer. In Experiment 1, spatial serial recall was combined with ocular suppression whereas articulatory suppression was used in Experiment 2.

EXPERIMENT 1

In this experiment, we examined the effect of ocular suppression on spatial serial recall and the path length effect. During item presentation, series of seven dots were presented sequentially on the computer screen. After the presentation of the sequence, all dots were re-presented simultaneously during seven seconds before recall. Tremblay et al. (2006) showed that when all dots are represented during the retention interval, participants tend to move their eyes from one dot to another in the same order in which they had been presented. This procedure has therefore proved to be a valuable method in order to examine the rehearsal activity taking place during a spatial memory task. In order to test whether the path length effect originates during encoding or rehearsal, a dual task procedure with an interfering task was used during the presentation of the items as well as during the retention interval. The interfering task consisted of moving the eyes incessantly between two crosses that appeared alternatively on each side of the window in which the dots were presented. In addition to preventing the use of eye movements, ocular suppression should also prevent attentional shifts to the dot locations. If the path length effect originates from processes required during encoding, the effect should be abolished when ocular suppression is carried out during item presentation. Alternatively, if the path length effect is mediated by rehearsal, ocular suppression carried out during the retention interval should abolish the path length effect.

One could argue that ocular suppression during item presentation might interfere with performance simply because moving the eyes prevents participants from accurately perceiving the dots. However, this possibility is unlikely because parafoveal vision is sufficient to allow adequate perception of dot locations. In support to this view, Smyth (1996) showed that performance was not altered when participants were required to process each location in periphery. Therefore, when participants are fixating the crosses on each side of the window during the suppression task, their perception of the dots presented in periphery should not be altered.

Eye movements were monitored during item presentation and the retention interval of the spatial serial recall task in order to explore the mechanisms responsible for the processing of spatial information and to examine how they are related to the path length effect. Several studies suggested that viewing time is an indication of the processing given to the stimuli based on the finding that fixation duration is positively related to recall performance (e.g., Hollingworth & Henderson, 2002; Saint-Aubin et al., 2007; Zelinsky & Loschky, 2005). To examine if processing time is related to the path length effect, fixation duration on the dots during item presentation was measured. In line with the idea that spatial rehearsal is based on eye movements (see Baddeley, 1986; Brockmole & Irwin, 2005; Lawrence et al., 2004; Lawrence et al., 2001; Pearson & Sahraie, 2003), Tremblay et al. (2006) reported that the order in which the different dots of a sequence are revisited through eye movements during a retention interval is related to performance. In order to measure the rehearsal activity carried out in the present study, the number of items fixated in the correct order during the retention interval was measured.

METHOD

Participants. Forty-two undergraduate students from Université Laval participated in the experiment in exchange for a small honorarium. All reported normal or corrected-to-normal vision.

Apparatus and materials. The course of the experiment was controlled by a PC computer using E-Prime, with a resolution of 1024 x 768 pixels. Participants were seated at approximately 60 cm from the computer screen. The stimuli were sequences of seven black dots of 1.3° in diameter, presented at different locations within a white window of 25° x 20°. One thousand sequences were randomly generated with the restriction that the total distance across all pairs of successive dots ranged from 46° to 49° in the short path condition and between 57° and 59° in the long path condition. All sequences were categorised according to the number of crossings they contained. Sixty sequences were retained for the experiment, half of which contained three crossings and the other half contained four crossings (see Parmentier & Andrés, 2006). The mean distance between successive dots was 10° (*SD* = 4.2°) in the short path condition and 15° (*SD* = 4.7°) in the long path condition. The spatial location of the dots varied across trials and all dots taken two by two within a sequence were separated by at least 4.5°.

The eye movements were recorded with the Tobii eye tracker (Tobii Technology, 2006). The system's resolution and sampling rate are 0.25° and 50 Hz. The eye movements were captured by a camera integrated at the bottom of the computer screen, at about 60 cm from the participants who were free to move their head.

Design. There were two repeated-measures factors: ocular suppression (3 levels; no suppression, suppression during presentation, suppression during delay) and path length (2 levels; short, long). The three suppression conditions were blocked and counterbalanced across participants. There were 20 trials in each block (10 short, 10 long), presented in a different random order for each participant. The three blocks of experimental trials were preceded by six practice trials, two in each of the suppression condition.

Procedure. Before the beginning of the memory task, the eye tracker system was calibrated: Participants were asked to fixate alternatively nine blue calibration dots. In each trial of the memory task, seven black dots were presented successively at a rate of one dot per second (1000 ms on/0 ms off). The last dot was followed by an empty delay of 500 ms after which all dots reappeared simultaneously in their original location during a retention interval of 7 seconds. After the retention interval, a 250 Hz tone was presented and the mouse cursor appeared on the screen to indicate to the participants to recall the sequence. They were required to click on the dots in the order in which they had been presented and were not allowed to skip a response. Each dot turned to blue once selected.

In the two ocular suppression conditions, two black crosses presented in Courier New, 40 point, appeared alternatively on each side of the window. They were located at 1° to the left and to the right of the window in which the dots were presented, centered on the vertical axis. Each fixation cross appeared during 500 ms and disappeared during 500 ms, so that when one cross was on, the other was off. When ocular suppression was carried out during the sequential presentation of the dots (suppression during presentation), the first cross appeared 500 prior to the onset of the first dot and the disappearance of the last cross was synchronised with the offset of the last dot. When ocular suppression was carried out during the retention interval (suppression during delay), the first cross appeared at the offset of the last dot, that is, 500 ms before the simultaneous presentation of all dots. The last cross' offset was synchronised with the presentation of the tone prompting recall. In both conditions, participants were instructed to move their eyes from one cross to the other incessantly. The three suppression conditions are illustrated in Figure 1.

The practice trials were done with the experimenter present to make sure that the participants understood how to perform the suppression task. Since eye movements could be followed on a second monitor during the practice trials, the experimenter could remind participants to fixate each cross as they appeared when they deviated from the task. The session lasted approximately 45 minutes.

RESULTS

Eye movements during the suppression conditions were recorded in order to verify if the ocular suppression task had been carried out adequately. When a fixation was made on a dot, or when one cross was skipped, resulting in a fixation duration superior to 1000 ms on one cross, an error was calculated. Sixteen trials out of 840 (42 participants x 20 trials) in the suppression during presentation condition and 18 in the suppression during delay condition were removed.

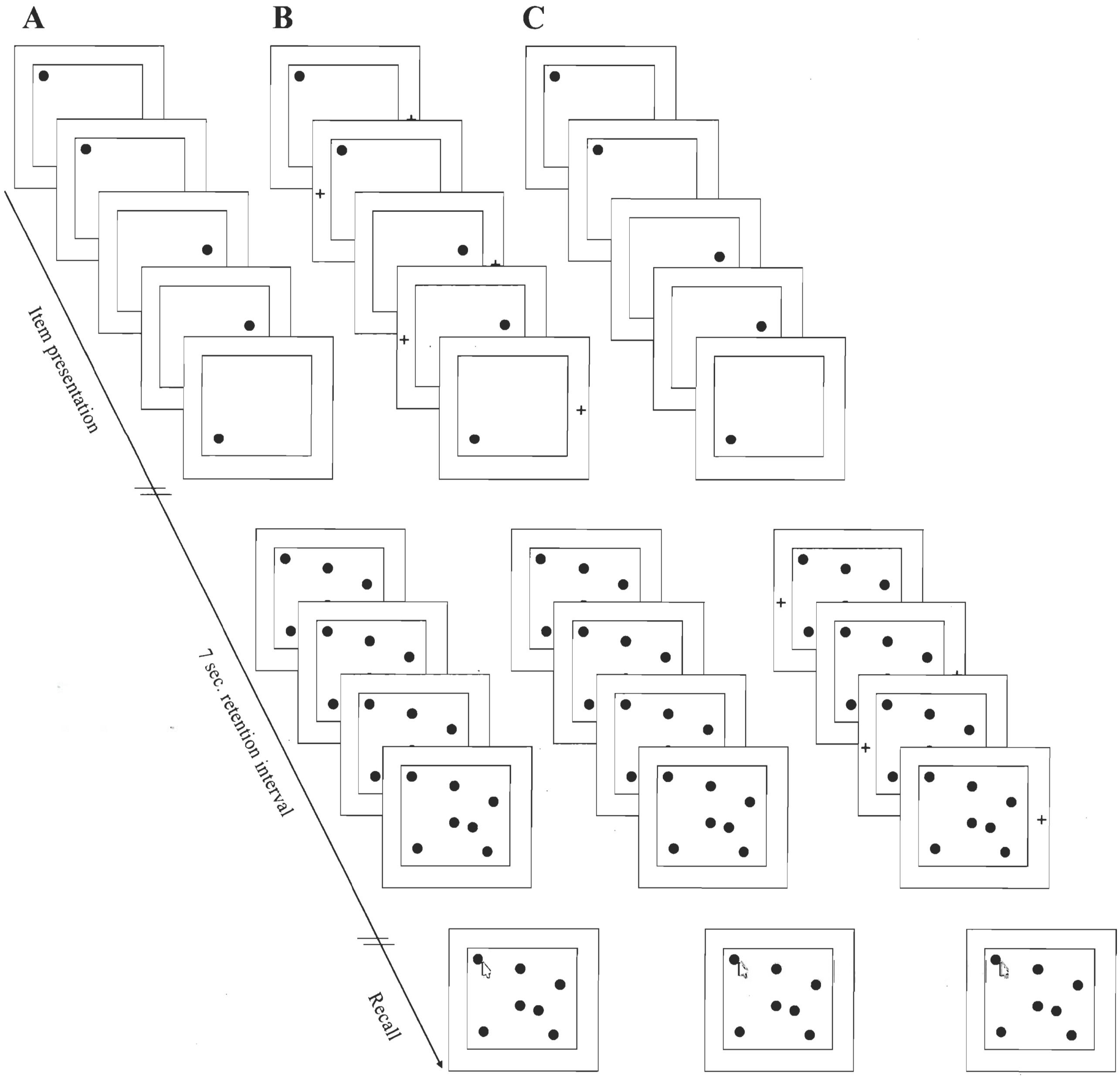

Figure 1. Illustration of the no suppression (A), suppression during presentation (B) and suppression during delay conditions (C) in Experiment 1. Each frame represents a timestamp of 500 ms. Only the first 2500 ms and 2000 ms of item presentation and retention interval are illustrated. Note that two frames are used to present a single dot during item presentation in order to illustrate the cross displacement.

Recall performance. Responses were corrected according to a strict serial recall criterion: a response was considered correct if the item was recalled in the same serial position in which it had been presented. Figure 2 shows that performance in the no suppression condition was higher for the short paths than for the long paths. When ocular suppression was carried out, whether it was during item presentation or during the delay, the path length effect appeared to be substantially reduced. A 3 (ocular suppression) X 2 (path length) repeated-measures analysis of variance (ANOVA) was performed on the proportion of correct responses. In all analysis, the .05 level of significance was adopted and the Greenhouse-Geisser correction was applied when sphericity was violated. The analysis revealed that performance varied between the different suppression conditions [$F(2, 82) = 77.67$, $MSE = 0.01$, $\eta^2_p = .65$], and was higher for the short paths than for the long paths [$F(1, 41) = 14.96$, $MSE = 0.01$, $\eta^2_p = .27$]. The significant interaction between ocular suppression and path length [$F(2, 82) = 5.01$, $MSE = 0.04$, $\eta^2_p = .11$] suggests that the path length effect was affected by ocular suppression. Indeed, performance in the short path condition was higher than in the long path condition in the no suppression condition [$t(41) = 3.83$, $p < .001$], but not in the suppression during presentation condition [$t(41) = 0.98$, $p = .33$], nor in the suppression during the delay condition [$t(41) = 1.38$, $p = .17$].

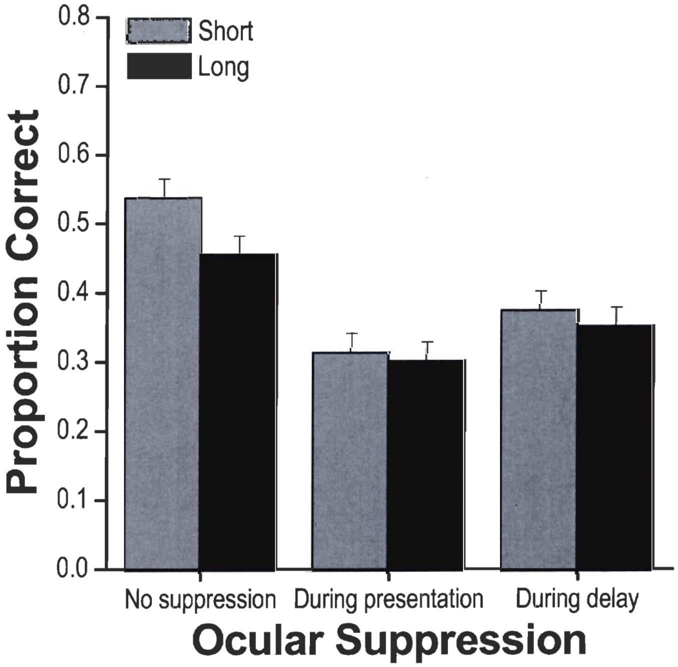

Figure 2. Proportion correct for the short and long path conditions in the no suppression, suppression during presentation, and suppression during delay conditions. Error bars represent 95% confidence intervals.

Pairwise comparisons showed that performance was significantly higher in the no suppression condition than when ocular suppression was carried out during the delay ($p < .001$), and that performance in the latter condition was significantly higher than when ocular suppression was carried out during item presentation ($p < .001$).

Fixation duration during item presentation. These analyses include eye movements recorded from the onset of the first dot until offset of the seventh dot in the no suppression condition and in the suppression during delay condition. A dot was considered fixated if the participants' gaze landed within its acceptance area. The acceptance area was centered at the actual position of the dot and its radius (2.25°) represents the middle point between the nearest two dots out of all 60 trials, so that there was no overlap between the acceptance areas of two dots in the same sequence. The acceptance area was constant across both trials and participants. Twenty trials out of 1680 (42 participants X 40 trials) were discarded due to large distortions in eye movement recordings.

In order for a fixation to be included in the analysis, the gaze landing position had to fall within the acceptance area of the presented dot before the onset of the next dot. The duration of a fixation was calculated until the onset of the next dot or until the next fixation, whichever was sooner. As shown in Figure 3, fixation duration appeared to be longer when suppression had to be carried out during the delay than in the no suppression condition, and longer in the short path condition than in the long path condition. A 2 (ocular suppression) X 2 (path length) repeated-measures ANOVA performed on fixation duration in the no suppression and suppression during the delay conditions confirmed that fixation duration was longer in the suppression condition than in the control condition [$F(1, 41) = 9.44$, $MSE = 6155.56$, $\eta^2_p = .19$] and longer in the short paths than in the long paths [$F(1, 41) = 104.39$, $MSE = 1580.72$, $\eta^2_p = .72$]. The interaction between ocular suppression and path length was not significant [$F < 1$].

The number of dots fixated in the correct order during the retention interval. These analyses include eye movements recorded from the offset of the seventh dot – that was replaced by the simultaneous presentation of all seven dots – until recall in the no

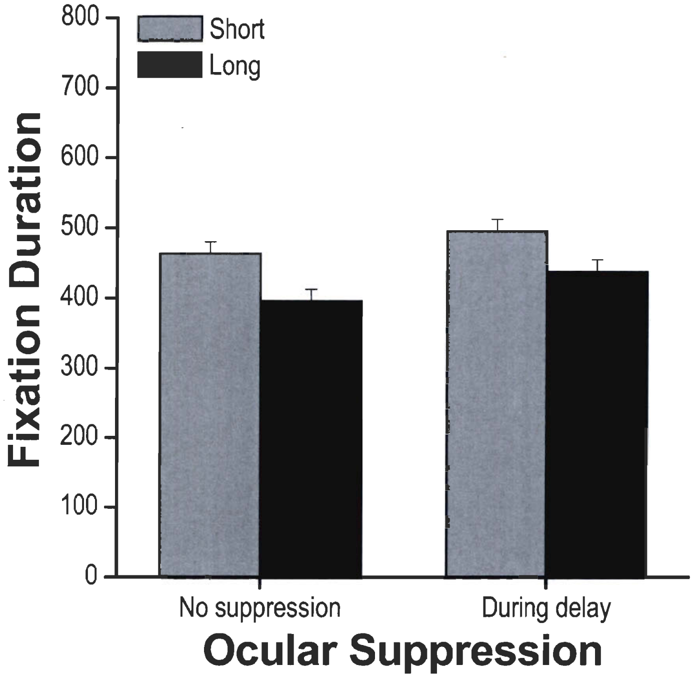

Figure 3. Fixation duration during presentation for the short and long path conditions in the no suppression and suppression during delay conditions. Error bars represent 95% confidence intervals.

suppression condition and in the suppression during presentation condition. When the eyes moved (i.e. when the participants made a saccade) between the acceptance areas of two successive dots in the same order in which they had been presented, we considered that pair of dots had been rehearsed (see Tremblay et al., 2006). Figure 4 shows that participants rehearsed more pairs in the short path condition than in the long path condition and more pairs in the no suppression condition than when ocular suppression had been carried out during presentation. This was confirmed by a 2 (ocular suppression) x 2 (path length) repeated measures ANOVA carried out on the number of pairs rehearsed per trial in the long and short paths of the no suppression and suppression during presentation conditions. One participant was removed from the analysis because no pair was rehearsed in the suppression during presentation condition. The analysis revealed that the number of dots fixated in the correct order was lower in the suppression condition than in the control condition [$F(1, 41) = 17.20$, $MSE = 0.31$, $\eta^2_p = .30$] and higher in the short path condition

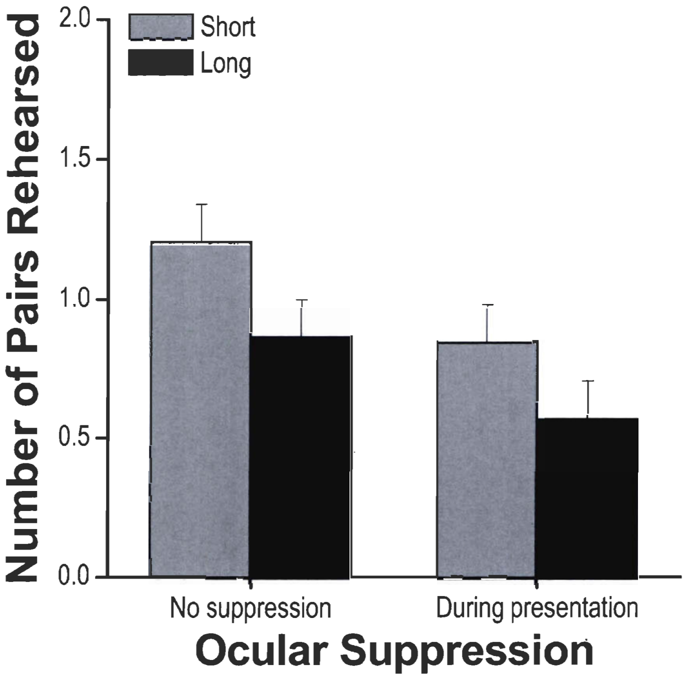

Figure 4. Number of pairs rehearsed during the retention interval for the short and long path conditions in the no suppression and suppression during presentation conditions. Error bars represent 95% confidence intervals.

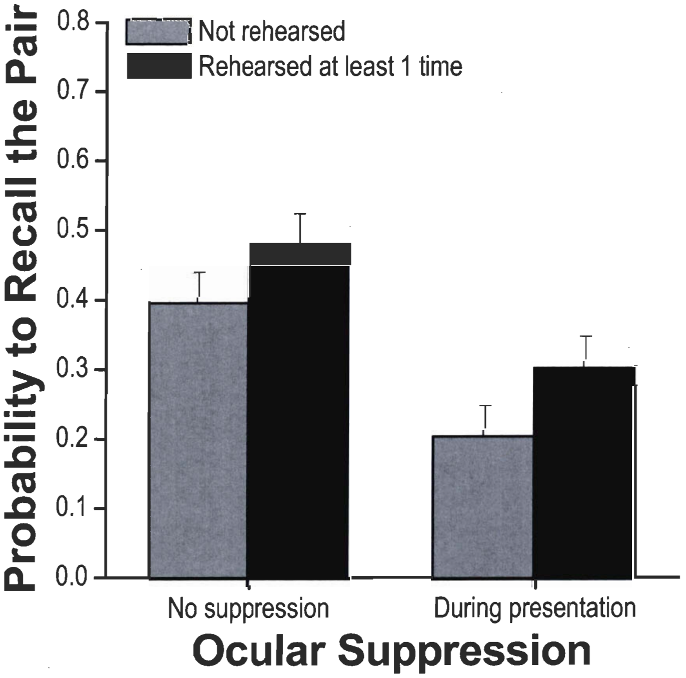

Figure 5. Probability to recall the pair as a function of the number of times the pair has been rehearsed during the retention interval in the no suppression condition and in the suppression during presentation condition. Error bars represent 95% confidence intervals.

than in the long path condition [$F(1, 41) = 35.67$, $MSE = 0.12$, $\eta^2_p = .47$]. The interaction between ocular suppression and path length was not significant [$F < 1$], suggesting that rehearsal was modulated by path length in both conditions.

We then tested whether the number of occasions a pair of successive dots had been rehearsed was related to the probability to recall that pair[1]. When the two items from a pair were recalled in the correct order, no matter in what serial position, the recall performance for that pair was set to 1, otherwise, the recall performance was 0. An examination of Figure 5 suggests that performance was higher in the no suppression condition than in the suppression during encoding condition, and that pairs rehearsed at least one time were better recalled than pairs not rehearsed. A 2 (ocular suppression) X 2 (rehearsal; not rehearsed, rehearsed at least 1 time) repeated-measures ANOVA was carried on the probability to recall the pair in the no suppression and suppression during presentation conditions. The analysis revealed that the probability to recall the pair was lower in the suppression during encoding condition compared to the no suppression condition [$F(1, 40) = 47.58$, $MSE = 0.03$, $\eta^2_p = .54$], and was lower when the pair was not rehearsed compared to when it was rehearsed at least one time [$F(1, 40) = 23.98$, $MSE = 0.01$, $\eta^2_p = .37$]. The interaction between ocular suppression and rehearsal was not significant [$F < 1$], suggesting that performance was higher for the pairs that had been rehearsed in both conditions.

DISCUSSION

In line with Parmentier et al. (2005) we observed that recall performance increased as the distance between successive locations decreased in a spatial serial recall task. Our results also showed that fixation duration during item presentation (see Saint-Aubin et al., 2007) and the number of pairs fixated in the correct order during a retention interval (see Tremblay et al., 2006) were modulated by path length and were higher in the short path than in the long path condition. Fixation duration was also influenced by ocular

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[1] Tremblay et al. (2006) analysed the recall performance for the trial as a function of the number of pairs rehearsed in the sequence. However, in our experiment, some participants had rehearsed at least one pair in each trial so that there were not enough observations for 0 pair rehearsed. Therefore, performance was computed as a function of the number of rehearsal per pair instead of as a function of the number of rehearsal per trial.

suppression: when participants had to suppress eye movements during the retention interval, their fixations during item presentation were longer than those in the no suppression condition. There is evidence that longer fixations can lead to stronger memory representations and consequently, enhance recall performance (Hollingworth & Henderson, 2002; Saint-Aubin et al., 2007; Zelinsky & Loschky, 2005). One explanation for the longer fixation duration is therefore that participants spent more time encoding each dot location when they had to suppress during the retention interval.

The abolition of the path length effect under ocular suppression is a critical finding in support of the view that eye movements play a key role in maintaining the advantage of short paths over long paths. The experimental manipulation of eye movements by the ocular suppression requirement is essential to establish their role in shaping the path length effect. However, as is the case with any secondary task, one could argue that the effect of ocular suppression is due to a general distraction effect rather than to its specific interference with the use of eye movements. In order to clearly establish the role of eye movements in the path length effect, another experiment was carried out to investigate whether a secondary task that is demanding but clearly does not prevent the use of eye movement would also abolish the path length effect. Such criteria are met by using articulatory suppression as a secondary task. Although articulatory suppression - whereby participants are required to repeatedly articulate some irrelevant speech sound (see Murray, 1968) - is typically used with verbal serial recall to prevent speech-based rehearsal and is predominantly detrimental of verbal STM performance, it has been shown to require attentional resources (see, e.g., Meiser & Klauer, 1999) and to impair spatial serial recall (e.g., Avons, 1998).

EXPERIMENT 2

In Experiment 2, we employed a dual task procedure in which articulatory suppression had to be performed in concurrence to the spatial memory task. Articulatory suppression was combined with spatial serial recall in order to examine whether a dual task procedure with no ocular suppression is sufficient to affect the path length effect.

METHOD

Participants. Forty-four undergraduate students from Université Laval participated in the experiment in exchange for a small honorarium. All reported normal or corrected-to-normal vision.

Apparatus and materials. The apparatus and materials were the same as in Experiment 1 except that half sequences contained 2 crossings and the other half contained 3 crossings.

Design. There was one between-subjects factor, articulatory suppression (2 levels; no suppression, with suppression) and one repeated-measure factor, path length (2 levels; short, long). There were 20 trials in each suppression group (10 short, 10 long), presented in a different random order for each participant.

Procedure. In each trial of the memory task, seven black dots were presented successively at a rate of one dot per second. After presentation, all dots reappeared simultaneously in their original location and participants were required to click on the dots in the order in which they had been presented. One group of participants executed this task alone (no suppression condition). In the articulatory suppression group, participants were required to articulate the letters from A to G at a rate of 3 letters/sec. They began the interfering task at the beginning of item presentation and stopped for recall. The session lasted approximately 30 minutes

RESULTS

Recall performance. Figure 6 shows that performance is better in the short paths than in the long paths in both suppression conditions: Interference does not seem to have altered the path length effect. A 2 (articulatory suppression) X 2 (path length) mixed-design

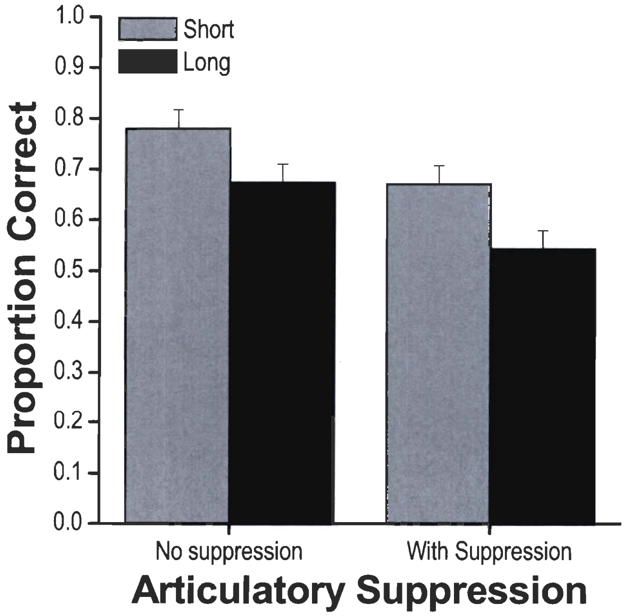

Figure 6. Proportion correct for the short and long path conditions in the no suppression and articulatory suppression conditions of Experiment 2. Error bars represent 95% confidence intervals.

ANOVA revealed that performance was higher in the no suppression condition than when articulatory suppression had to be carried out [$F(1, 42) = 8.89$, $MSE = 0.04$, $\eta^2_p = .18$], and was higher for the short paths than for the long paths [$F(1, 42) = 46.82$, $MSE = 0.01$, $\eta^2_p = .53$]. The interaction between articulatory suppression and path length was not significant [$F < 1$], confirming that the path length effect did not differ between the two suppression conditions.

DISCUSSION

The results of Experiment 2 replicated those of Experiment 1 and further established the robustness of the effect by revealing that the path length effect is unaffected by the presence of a retention interval (see also Parmentier & Andrés, 2006). Most importantly, the results of Experiment 2 show that articulatory suppression did not alter the path length effect – though, as expected, suppression reduced overall recall performance. This pattern of results suggests that the abolition of the path length effect in Experiment 1 is not due to some general distraction effect. As such, the results clearly show that the mere reduction of recall performance is not sufficient to abolish the advantage of short paths over long paths.

GENERAL DISCUSSION

The objective of the present study was to investigate the mechanisms implicated in the short-term recall of visual-spatial information by examining the path length effect combined with an analysis of eye movements. Experiment 1 showed that when eye movements are suppressed during item presentation or the retention interval, the path length effect is abolished. Experiment 2 confirmed that this effect is not due to the use of a dual task procedure since articulatory suppression, although it impaired performance, did not alter the path length effect.

REHEARSAL-BASED ACCOUNTS

When ocular suppression was carried out during the retention interval, the path length effect was abolished. It is widely assumed that the processes called upon during a retention interval are mainly related to rehearsal (see, e.g., Jones et al., 1995; Meiser & Klauer, 1999). Therefore, the finding that ocular suppression during the retention interval eliminated the path length effect strongly suggests rehearsal is a critical factor in shaping the effect. In line with this hypothesis, the analysis of eye movements revealed that during a retention interval, more pairs of successive dot locations were rehearsed in the short path condition than in the long path condition (see Tremblay et al., 2006). That ocular suppression carried out during item presentation abolished the path length effect can also be accounted for by a rehearsal-based explanation: Although rehearsal is known to take place during a retention interval, it is also required during item presentation in order to prevent the forgetting of the just-encoded locations during the encoding of the new locations (see Meiser & Klauer, 1999).

The most common account of rehearsal comes from the Working Memory model (WM; Baddeley, 1986, 2000; Baddeley & Hitch, 1974), where rehearsal is viewed as a mechanism responsible for refreshing the activation of items maintained in memory. The capacity of this mechanism to maintain TBR items activation is severely limited by the time required to recirculate information because items are assumed to decay very rapidly from memory (e.g., see Baddeley, Thomson, & Buchanan, 1975). The effectiveness with which representations in WM can be rehearsed is therefore determinant of recall performance. In the verbal domain, the use of an articulatory control process at the basis of rehearsal of verbal information is now well established (Schweickert & Boruff, 1986). In the spatial domain, the nature of rehearsal is still a matter of debate. In the context of the WM model, spatial information is processed by a specialised sub-system, that is the visuo-spatial sketch pad (see Logie, 1995). It is the interaction between a passive temporary store for visual information (visual cache) and an active mechanism involved in the rehearsal of temporal and spatial information (inner scribe) that is held responsible for performance in spatial serial recall. While items stored in the visual cache decay rapidly, the action of the inner scribe keeps them active for recall. Baddeley (1986) suggested that the inner scribe, and therefore spatial rehearsal, could be based on eye movements. A related idea is that the mechanisms implicated in the planning and control of movements are also responsible for the processing of spatial information (see Logie, 1995; Smyth, Pearson, & Pendleton, 1988). A more recent account however, suggests that spatial shifts of attention to the memorised locations would serve the purpose of increasing their activation (Awh, Jonides, & Reuter-Lorenz, 1998). Path length can therefore be seen as modulating the number of items that can be reactivated: As the time to revisit the dots' representation in memory increases, the decay rate of the memory traces becomes faster than their refreshing rate. One assumption that comes with the latter explanation is that there is a direct relation between the time to actually scan the presented sequence and the time to mentally scan it. Following the pioneer work of Kosslyn, Ball, and Reiser (1978) on mental imagery, it is widely acknowledged that the time required for shifting attention from one location to another onto a mental representation is similar to that required for shifting attention across locations on a real object, that is, it increases as a function of the distance separating these locations. This idea however, may seem at odd with the results of Smyth and Scholey (1992, 1994). The authors manipulated the size of the display in a Corsi block task and showed that performance was not modulated by display size. The discrepancy between our results and theirs suggests that spatial information is represented in memory using relative rather than absolute distances. In other words, even though the relative distance between objects within the same display seems to be preserved in memory, the absolute size of the display would not. Further research is required to test the distinction between absolute and relative distances within a spatial configural display.

Another account of rehearsal comes from the Perceptual-Gestural View (see Jones, Hughes, & Macken, 2006) according to which rehearsal is used in order to form a sequence of motor actions through which the TBR material is encoded and maintained. The retention of serial information depends on the efficacy of specific skills to form a fluent sequence from the TBR items. This view was mainly applied to auditory-verbal information, where performance is related to articulatory abilities such as co-articulation or intonation. In other words, sequences of items that are easier to articulate during rehearsal are also better recalled (Murray & Jones, 2002; Woodman, Macken, & Jones, 2008). Similar assumptions could be applied to the spatial domain, where oculomotor movements would be held responsible for the rehearsal of visuo-spatial information (see Tremblay et al., 2006). Several factors are known to influence eye movements, such as the distance travelled by the eyes. For example, saccades made over long distances take longer to plan (Viviani & Swensson, 1982), longer to execute (Abrams et al., 1989) and are less precise (Abrams et al., 1989) than those made over short distances. According to this view, the number of locations that can be rehearsed during a given period of time is not the main factor reducing the efficiency of rehearsal. Instead, rehearsal would be limited because the series of motor actions required to rehearse long paths would be less coherent and organised than those required to rehearse short paths.

ENCODING-BASED ACCOUNTS

One challenge in memory research is to empirically disentangle between rehearsal and other processes at play during the presentation of items. It is therefore possible that path length affects encoding processes and that the path length effect was abolished because the use of ocular suppression during item presentation altered other processes than rehearsal. One factor that was shown to contribute to encoding efficiency is the time available to process each location (see Saint-Aubin et al., 2007). Indeed, our results showed that fixation duration was longer in the short path condition than in the long path condition. Since fixation duration is positively related to recall performance and taking into account the widely accepted assumption that fixation is associated with the quality of the encoded memory representations (see Hollingworth & Henderson, 2002; Saint-Aubin et al., 2007), the path length effect may occur as a result of the relatively poor encoding of spatial information in the long path condition compared to the short path condition.

In line with the encoding-based hypothesis, we observed that when ocular suppression had been carried out during item presentation, the number of pairs fixated in the correct order remained greater for the short paths than for the long paths. This finding suggests that path length might influence some memory processes during item presentation that are not captured through the analysis of performance in serial recall. For example, Dent and Smyth (2006) showed that using a sequential presentation with more than six items, locations were coded relatively to the overall configuration of the sequence, that is, locations are encoded in relation to each other rather than independently. Moreover, Woodman, Vecera, and Luck (2003) suggested that items presented close in space are more likely to be perceived as a group and encoded in relation to each other than items presented far from each others (see also Jiang, Olson, & Chun, 2000). One explanation is therefore that because the dots in the long paths are very far apart, long paths may disrupt the perception of the order cues that serve to organise the list in memory (see Parmentier, Maybery, Huitson, & Jones, 2008). According to the Perceptual-Gestural view (e.g., see Jones et al., 2004, 2006), perceptual factors play a crucial role in memory and performance depends on the extent to which incoming information can be organised to form a stream of objects (i.e. in opposition to perceived in isolation). The path length effect could therefore occur – at least in part – because increasing path length disrupts the perceptual organisation of the sequence by preventing the perception of transitions between consecutive items. Moreover, since perceptual organization processes are pre-attentive (see Macken & Jones, 2003; Treisman, 1988), one can argue that suppression should not alter effects yielded by perceptual organisation. This would explain why the path length effect survived suppression, at least as measured by the eye movement analysis.

Based on the finding that the correspondence between the number of pairs rehearsed and serial recall performance in relation to the impact of path length is not perfect, one could be tempted to question the relationship between eye movements and spatial memory. Indeed, we cannot exclude the possibility that rehearsal, and so retention-oriented eye movement, exert little influence on the retention of items in memory and that other factors such as distinctiveness are at play (see, e.g., Nairne, 2002). However, in the present study and in several previous studies (Hollingworth & Henderson, 2002; Saint-Aubin et al., 2007; Tremblay et al., 2006; Zelinsky & Loschky, 2005), eye movements and performance were shown to be closely related. For example, Zelinsky and Loschky (2005) showed that the order in which the items are fixated is related to recall performance (see also Tremblay et al., 2006). It is therefore safe to conclude that eye movements play a key role in the processing of spatial information and constitute a more sensitive and online measure of memory processes.

In conclusion, the present study shows that eye tracking may provide a finer grained evaluation of the cognitive processes active during the encoding and rehearsal of spatial information, since eye movements were affected by path length to a greater extent than performance, as revealed by the analysis of rehearsal. Together with the effect of ocular suppression, the pattern of eye movements suggests that path length modulates rehearsal efficiency, and therefore, that eye movements are critical for maintaining spatial information. A Working Memory perspective would suggest that eye movements are used in order to reactivate the dot locations in memory (e.g., see Baddeley, 1986). Another view, that of the perceptual-gestural framework, would propose that eye movements are critical to translate the dot locations into a series of motor actions (e.g., see Jones et al., 2006).

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CHAPITRE IV

RÉCONCILIER LA PRÉSENCE DE SIMILITUDES ET DE DISSOCIAITONS EN MÉMOIRE

RÉSUMÉ

Le traitement de l'ordre et la rétention de l'information à court terme joue un rôle central dans une panoplie d'activités quotidiennes. Depuis les 30 dernières années, les démonstrations de dissociations neurologiques et comportementales entre la rétention de l'information verbale et spatiale ont mené à l'adoption d'une vision modulaire selon laquelle le traitement de l'information verbale et celui de l'information spatiale seraient supportés par des modules indépendants (e.g., Baddeley & Hitch, 1974). La démonstration de similitudes fonctionnelles entre le verbal et le spatial cependant, remet en doute la nécessité de recourir à des modules indépendants afin d'expliquer la rétention de l'information (l'approche unitaire; e.g., Cowan, 1999; Jones, Beaman, & Macken, 1996). Chacune des approches modulaire et unitaire est supportée par des résultats qui sont difficiles à expliquer par la vision opposée. L'objectif de ce chapitre est de faire un relevé des démonstrations à l'appui et à l'encontre de la vision modulaire et de considérer les alternatives qui pourraient permettre de réconcilier l'existence de similitudes fonctionnelles et de dissociations entre la rétention de l'information verbale et celle de l'information spatiale.

IMMEDIATE MEMORY FOR VERBAL AND SPATIAL INFORMATION: RECONCILING FUNCTIONAL SIMILARITIES AND DISSOCIATIONS

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ABSTRACT

The processing of serial order and retention of information over the short term underpin a wide range of cognitive activities. Over the last 30 years or so, evidence of behavioral and neuroimaging dissociations between the processing of verbal and that of spatial information has led to the adoption of the modular view according to which verbal and spatial immediate memory rely on distinct structures (e.g., Baddeley & Hitch, 1974). Functional similarities between the spatial and verbal domains however, provide support for unitary views of immediate memory that challenge the idea of separate memory stores (e.g., Cowan, 1999; Jones, Beaman, & Macken, 1996). Each approach is supported by data that are rather difficult to account for by the opposite view. In the present article, our objectives are to review the evidence in favor and against modularity and to consider alternatives that would be good candidates for reconciling evidence of functional similarities and of dissociations.

INTRODUCTION

The limited capacity to remember events in a particular order has been a concern for over a century (e.g., Conrad, 1965; Ebbinghaus, 1885) and continues to be a key topic of study within experimental psychology (see, e.g., Baddeley, 2001; Marshuetz, 2005; Nairne, 2002, for reviews). The temporary retention of information and the processing of serial order are essential aspects of human cognition as they underpin a wide range of cognitive functions and behaviors (e.g., Acheson & MacDonald, 2009; Gathercole & Baddeley, 1993; Lashley, 1951; Murdock, 1968). Most studies in immediate memory[1] use verbal material, though there is a growing interest for the retention of other types of information, such as spatial information (Avons, 1998; Smyth & Scholey, 1992; Zimmer, 1998). Verbal stimuli include items that can be articulated, such as words or digits, whereas spatial information refers to the location of an item in space (Wager & Smith, 2003). Whether the retention of information relies on separate or common mechanisms across verbal and spatial domains is still a matter of debate. The modular view[2], such as that exemplified by the Working Memory (WM) model (e.g., Baddeley & Hitch, 1974; see also Jonides & Smith, 1997; Wickens, 1992), suggests that separate memory structures are responsible for the retention of verbal and spatial materials, and that double dissociations between the verbal and spatial domains reflect the functional dissociation between these stores. Double dissociations have been found in the context of neuroimaging and behavioral studies. Neurological dissociations are shown when verbal and spatial memory tasks activate different brain regions – that is, the left hemisphere for verbal information and the right hemisphere for spatial information (e.g., see Smith, Jonides, & Koeppe, 1996) – whereas

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[1] From hereon the term 'immediate memory' is used rather than short-term or working memory as short-term memory assumes a separation between short- and long-term stores and working memory is related to a particular view of memory. However, all studies reviewed here are concerned with so-called short-term memory and working memory research.

[2] In the present review modularity refers to the division of memory into separate modules based on the nature of the information. This application of the modularity concept is different than the classical theory of modularity proposed by Fodor (1983) in which input processes such as pattern recognition are viewed as modular whereas higher level processes such as problem solving are non-modular. Another modular division is that between short- and long-term stores (e.g., Atkinson & Shiffrin, 1968; Baddeley, 2001). The latter distinction, though well-accepted by the vast majority of researchers, has been challenged in a seminal paper by Crowder (1982, see also Cowan, 1995; Ericsson & Kintsch, 1995). The current review focuses on the fractionation between verbal and spatial components of immediate memory and does not directly tackle the long- and short-term distinction, although the procedural views presented in this chapter are not entirely consistent with the idea of separate short- long-term memory stores.

behavioral dissociations occur when verbal and spatial interfering tasks selectively impair performance in verbal and spatial memory tasks respectively (e.g., Meiser & Klauer, 1999).

An alternative view is that the processing of verbal and that of spatial material in immediate memory both utilize the same cognitive operations, one consequence of which is the production of similar patterns of performance (e.g., Jones, Farrand, Stuart, & Morris, 1995; Smyth, Hay, Hitch, & Horton, 2005; Ward, Avons, & Melling, 2005; see also Cowan, 1999; Neath & Fortin, 2005). Numerous studies have provided evidence of functional similarities across the verbal and spatial domains. For example, the retention of both types of information produces similar serial position curves (e.g., Tremblay, Parmentier, Guérard, Nicholls, & Jones, 2006) and equivalent distributions of errors (e.g., Guérard & Tremblay, 2008). A number of studies also provided evidence of cross-domain interference by showing that a verbal activity may alter performance in a spatial memory task (e.g., Jones et al., 1995; Morris, 1987; Smyth & Pelky, 1992) and inversely, that a spatial activity may disrupt the retention of verbal information (e.g., Larsen & Baddeley, 2003). Such a pattern of findings suggests that some processes are shared between the verbal and spatial domains.

In order to make significant progress in modeling immediate memory, a model should account for dissociations as well as functional similarities between the verbal and spatial domains. Both sets of findings however, are difficult to reconcile because they are considered as evidence for two opposing views of memory, namely the modular and unitary accounts. The intention of the present article is to provide a thorough and critical review of the evidence both in favor of and against modularity. Neuroimaging and behavioral demonstrations of double dissociations are first presented, followed by a review of studies showing cross-domain interference and functional similarities between the retention of spatial and that of verbal information. We then discuss these findings in light of the predominant models of immediate memory and show that most of them have difficulties in handling some key relevant findings. Finally, we consider the perceptual-gestural view of memory (e.g., see Jones, Hughes, & Macken, 2006), which we suggest may be a good candidate for reconciling the existence of dissociations and similarities within a single framework.

BEHAVIORAL AND NEUROIMAGING EVIDENCE

CLASSICAL SERIAL MEMORY TASKS

In relation to the theoretical development and modeling of immediate memory, an abundant amount of data has been collected with seriation-based paradigms in which participants must recall sequences of items in a specific order. Performance in such tasks served as the basis for influential models of immediate memory such as the WM model (Baddeley, 1986). The most usual method for studying immediate memory is to present a participant with a relatively short sequence of familiar items (e.g., 6, 7, or 8 letters, digits, or words) and to require the reproduction of the sequence in its correct order. The serial recall task involves the recall of both items and their order of presentation; unless the same closed set of items is used throughout an experiment, in which case the burden of processing falls entirely on recalling their order. In another common procedure, that of order reconstruction, recall consists of re-presenting simultaneously all list items for participants to place them in the same order they were initially presented. As is the case for serial recall with a closed set, order reconstruction mainly requires the recall of order information (see Neath, 1997, for a discussion). Corsi (1972; see also Milner, 1971) designed a spatial version of order reconstruction. In the so-called Corsi block task, participants are presented with a set of squares placed at different locations. In the computer generated version, the presentation of the sequence consists of illuminating a number of squares one by one in a random order on the computer screen. During recall, participants have to reproduce the sequence using the mouse or a touch screen (see e.g., Berch, Krikorian, & Huha, 1998; Pearson & Sahraie, 2003; Smyth, 1996; Smyth & Scholey, 1994; Vandierendonck, Kemps, Fastame, & Szmalec, 2004). Another example of a spatial memory task is the dot task in which spatially distributed dots appear and disappear sequentially on the computer screen (e.g., Jones et al., 1995; see also Farrand & Jones, 1996). At recall, all dots reappear simultaneously and participants are required to select the dots in the same order in which they had been presented. In the context of memory research, the dot task may be used in preference to the Corsi block task because the former reduces the likelihood of verbal recoding by using changing random spatial locations for every trial (see, e.g., Berch et al., 1998; Couture & Tremblay, 2006, for a discussion). Also, the dot task allows more flexibility for manipulating the visual and spatial characteristics of the to-be-remembered (TBR) sequences (see Parmentier, Elford, & Maybery, 2005).

When comparing the processing of verbal and spatial information in memory, it is critical that great care is taken to equate the verbal and spatial tasks in every respect except for the TBR information to ensure that dissociations do not occur as a result of methodological differences (see, e.g., Smyth et al., 2005; Ward et al., 2005, for a discussion). Often, particularly in the case of neuroimaging studies, comparisons between the verbal and spatial domains are made across studies. Consequently, the memory tasks employed for these comparisons are seldom equated in terms of processing or task requirements (see Nystrom et al., 2000, for a discussion). Even when comparisons are made within a single experiment, some authors alluded to the possibility that great care was not always taken in equating the task requirements in the verbal and visual-spatial variants (see, e.g., Henson, Hartley, Burgess, Hitch, & Flude, 2003; Ward et al., 2005). For example, Meiser and Klauer (1999) showed a double dissociation using spatial and verbal reconstruction tasks. In spatial reconstruction, the set of spatial locations remained visible to participants throughout the whole experimental session whereas in verbal reconstruction, verbal stimuli appeared and disappeared sequentially on the computer screen. Moreover, in order to equate the level of performance between tasks, the number of TBR items differed between the spatial and verbal memory tasks, as well as the rate of item presentation. Double dissociations therefore, may not be related to differences in the content of the TBR material, but to other methodological differences.

EVIDENCE OF MODULARITY

Neuroimaging studies. Evidence for a fractionation between verbal and spatial memory components mainly comes from double dissociations in behavioral and neuroimaging studies. Neurological dissociations between verbal and spatial memory tasks appear to be lateralized with left and right hemispheres respectively associated with verbal and spatial components of memory (see, e.g., Jonides, Sylvester, Lacey, Wager, & Nichols, 2003; Reuter-Lorenz et al., 2000; Smith et al., 1996). However, before concluding that spatial and verbal materials activate separate brain regions corresponding to independent memory stores, one has to make sure that 1) the dissociation between the retention of verbal and spatial information is not due to different methodologies (see D'Esposito et al., 1998; Nystrom et al., 2000, for a discussion), 2) the observation of a neurological dissociation is systematic and observed when verbal and spatial memory tasks are compared directly within the same experiment (see Walter et al., 2003, for a discussion), and 3) the dissociation cannot be attributable to the fact that the spatial and verbal memory tasks recruit different rehearsal strategies (see Wager & Smith, 2003, for a discussion). We will address these three points in turn.

As pointed out by Nystrom et al. (2000; see also D'Esposito et al., 1998), convincing evidence for a dissociation between the spatial and verbal domains can only be demonstrated using equivalent spatial and verbal memory tasks administered to the same participants within the same experiment. Otherwise, it is impossible to compare the degree to which each brain area is activated by the spatial and verbal memory tasks. A noted by Nystrom et al. (2000) however, is that very few studies report neurological dissociations between verbal and spatial information within a single experiment. The reason for this is not clear, but one possibility is that several attempts have been made and that no differences emerged. Null effects however, tend no to be published.

In relation to the systematicity of neurological dissociations, the pattern of activation associated with performing verbal and spatial memory tasks appears to be largely inconsistent across studies (see Walter et al., 2003, for a discussion). A number of researchers employed similar memory tasks and observed very different patterns of activation (e.g., D'Esposito et al., 1998; Nystrom et al., 2000; Ray, Mackay, Harmer, & Crow, 2008; Reuter-Lorenz et al., 2000; Smith et al., 1996; Walter et al., 2003). For example, Smith et al. used positron emission tomography (PET) in combination with verbal and spatial versions of the *n*-back task. Participants were presented with a series of letters presented at different locations on the display. Their task was to indicate whether the item's identity (verbal task) or its spatial location (spatial task) was the same as that presented *n* items previously in the sequence. Brain activation in this condition was contrasted to that in a control condition. In the latter, participants had to indicate whether or not each item matched one of the three items memorised at the beginning of the experiment (item recognition). Smith et al. reported that the verbal and spatial *n*-back tasks respectively activated left and right hemisphere regions of the brain (see also Reuter-Lorenz et al., 2000). Spatial memory activated Brodmann's areas 7, 40 and 46 of the right hemisphere whereas verbal memory activated areas 40, 44 and 46 of the left hemisphere. This conclusion, however, rests on a visual not a statistical comparison. Moreover, the use of item recognition as a control may be problematic since this task also requires storage of information: participants have to memorize a set of three items at the beginning of the experiment for later comparison. Activation related to the storage of information in the *n*-back tasks is thus likely to have been discarded by subtracting activation in item recognition from activation in the *n*-back task. Therefore, conclusions can hardly be drawn regarding the existence of different memory stores based on their pattern of activation.

Nystrom et al. (2000; see also D'Esposito et al., 1998) used *n*-back tasks similar to those employed by Smith et al. in combination with functional magnetic resonance imaging (fMRI). As a control, they used a 0-back task in which participants were required to detect the presence of a given target in the series – for example, the letter "X". A direct statistical comparison showed that the spatial and verbal memory tasks activated the same brain regions, although some areas were more activated during the spatial task (e.g., Brodmann's areas 6, 8 in both the right and left hemispheres), and other areas were more activated during the verbal task (e.g., Brodmann's areas 32). Ray et al. (2008) also made direct statistical comparisons between regions activated during the retention of verbal and spatial information in *n*-back tasks. FMRI data analysis showed that some brain regions were activated to the same degree by the retention of verbal and spatial materials – the bilateral frontoparietal circuit. Although they also showed that some areas were more activated during the verbal task – Brodmann's areas 6 and 44 in the left hemisphere – this was not the case for the spatial task. Given these inconsistencies, it seems rather unsafe to conclude that the retention of verbal and spatial information relies on distinct circuitry or brain regions.

Even though neuroimaging data seem to be inconsistent, some studies do report domain specificity (e.g., see Reuter-Lorenz, 2000; Smith et al., 1996; Walter et al., 2003).

One possibility is that neurological dissociations appear because different rehearsal strategies are used for remembering verbal and spatial information (Wager & Smith, 2003). Rehearsal of verbal items is assumed to be closely related to the use of language or inner-speech (Murray, 1968; Schweickert & Boruff, 1986), whereas rehearsal of spatial information may involve shifts of spatial attention (Awh & Jonides, 1998, 2001; Awh, Jonides, & Reuter-Lorenz, 1998) or eye movements (Lawrence, Myerson, & Abrams, 2004; Tremblay, Saint-Aubin, & Jalbert, 2006). As will be discussed later, different rehearsal strategies do not imply that separate memory stores are involved in the processing of verbal and spatial information, and the use of different rehearsal strategies could be responsible for producing neurological dissociations (Courtney, Petit, Haxby, & Ungerleider, 1998; Wager & Smith, 2003). Indeed, brain regions preferentially activated by the retention of verbal information – that is, the Broca's area (Walter et al., 2003; Ray et al., 2008; Smith et al., 1996) – have been associated with verbal rehearsal and articulation (see Awh et al., 1996; Smith & Jonides, 1999). Similarly, the right ventrolateral prefrontal cortex preferentially activated by the retention of spatial information has been associated with spatial rehearsal (see Owen, Evans, & Petrides, 1996).

In sum, neuroimaging evidence for a fractionation between the verbal and spatial domains is clearly inconsistent across studies and when dissociations are reported, they can not be attributed unambiguously to the existence of separate memory stores. What, then, is the alternative explanation for domain specificity in the brain? Owen et al. (1996) suggest that areas in the frontal cortex are organised by process rather than by content (see also Courtney et al., 1998; D'Esposito et al., 1998; Miller, 2000; Nystrom et al., 2000; Wager & Smith, 2003; Walter et al., 2003). For example, D'Esposito et al. showed that tasks requiring passive storage of information activated mostly the ventral prefrontal cortex whereas tasks involving some form of manipulation (e.g., updating) seem to recruit the dorsal prefrontal cortex for both spatial and verbal information. Such an interpretation is similar to the idea that recall performance depends on the processes that are called upon in a memory task rather than the type of TBR information (see, e.g., Jones & Tremblay, 2000) and is consistent with unitary views of memory suggesting that the same processes may be responsible for retaining verbal and spatial information (see Cowan, 1999; Jones et al., 2006; Jones, Macken, & Nicholls, 2004).

Behavioral studies. In the case of behavioral dissociations, the typical experimental design requires participants to perform two tasks simultaneously. When both tasks involve material from the same domain of information (e.g., both tasks involve verbal stimuli), recall performance is markedly impaired relative to a condition in which they are of different contents (one task is verbal whereas the other is spatial). One of the most often cited observation of behavioral double dissociation was reported by Farmer, Berman, and Fletcher (1986). The authors tested the impact of spatial tapping and articulatory suppression on verbal and spatial reasoning tasks. For the tapping task, participants had to press on a series of keys one key at a time. As for articulatory suppression, participants were required to utter irrelevant items at a constant rate (Murray, 1968). During verbal reasoning, participants had to choose which of two pairs of letters corresponded to a sentence (e.g., which of “AB” or “BA” corresponds to the sentence “A is not followed by B”). Spatial reasoning required participants to indicate which of two shapes corresponded to a probe. Farmer et al. observed that spatial tapping interfered with spatial reasoning, while the same interfering task had no effect on verbal reasoning. Conversely, articulatory suppression disrupted verbal but not spatial reasoning. Although this study is seen by many as a demonstration of fractionation in immediate memory (e.g., Cocchini, Logie, Della Sala, Macpherson, & Baddeley, 2002; Meiser & Klauer, 1999; Salway & Logie, 1995), it is not clear whether the reasoning tasks employed by Farmer et al. involve immediate memory as typically assessed with serial memory tasks. Indeed, these tasks are more similar to visual perceptual tasks where participants have to indicate whether two visual stimuli are similar or different (e.g., García-Ogueta, 1993) than to tap on memory for order.

In a study using order reconstruction tasks, Meiser and Klauer (1999) also observed a dissociation between memory for verbal and that for spatial information. Participants were presented with series of either seven spatial locations or nine verbal items respectively drawn from pools of nine and 12 items. During recall, all nine or twelve items were re-presented simultaneously on the screen and participants had to reconstruct the original sequence. The Corsi blocks and letters were used as TBR items. Spatial and verbal reconstruction tasks were used in combination with either spatial tapping or articulatory suppression. The results showed that verbal reconstruction was disrupted more severely by articulatory suppression than by spatial tapping and that the Corsi block task was only affected by spatial tapping. Such behavioral double dissociations have been reported by a number of researchers with a variety of tasks (e.g., Guérard & Tremblay, 2008; Logie, Zucco, & Baddeley, 1990; Salway & Logie, 1995; see however, Jones et al., 1995).

Several researchers have argued that behavioural double dissociations are indicative of a fractionation between verbal and spatial stores in memory (e.g., see Meiser & Klauer, 1999). However, this interpretation has recently been challenged (e.g., Brown & Lamberts, 2003; Dunn & Kirsner, 2003; Plaut, 2003) and double dissociations were simulated from unitary systems (e.g., Plaut, 2003; see also Oberauer & Kliegl, 2006). Double dissociation has proved a valuable tool in experimental psychology and is certainly more powerful than correlational studies in testing theoretical models (see Baddeley, 2003b; Brown & Lamberts, 2003, for a discussion). We therefore suggest that double dissociations should be accounted for by models of immediate memory, but that they do not necessarily support a modular view. More importantly, the modular view has difficulties accounting for other, equally important lines of evidence, that is, demonstrations of functional equivalence between the retention of verbal and spatial information.

EVIDENCE OF FUNCTIONAL EQUIVALENCE

Evidence of functional equivalence relies on two types of empirical demonstrations: functional similarities and cross-domain interference. When both the verbal and the spatial memory tasks are fully equated in terms of processing requirements, a number of canonical verbal phenomena extend to the spatial domain (*functional similarities*; e.g., see Tremblay, Parmentier et al., 2006; Ward et al., 2005). An example of verbal and spatial order reconstruction tasks that are equated in terms of response procedure (e.g., reconstruction using mouse clicks) and type of presentation (sequential) is illustrated in Figure 1. These tasks are verbal and spatial versions of the order reconstruction procedure for which the only difference is the type of TBR material. Several studies have also shown disruption occurring between tasks that require the processing of different types of material (*cross-*

domain interference; e.g., see Jones et al., 1995; Jones & Macken, 1993; Morris, 1987). Such evidence of functional equivalence has usually been taken as support for the assumption that common mechanisms are at play whether the TBR information is verbal or spatial (e.g., see Jones et al., 1995). Demonstrations of functional similarities are first reviewed, including serial position curves, the modality effect, the distribution of errors, the effects of perceptual distinctiveness, of temporal grouping and of Hebb repetition. We then present evidence of cross-domain interference and the implications for models of immediate memory.

Serial position curves. One important result of retaining the order of events in immediate memory is the variation of recall accuracy as a function of the position of items within a sequence, what is known as the serial position curve. Relative to the middle of the list, recall is better for items at the beginning – the primacy effect – and at the end – the recency effect – of a sequence (see Murdock, 1968; Oberauer, 2003). Some researchers suggested that the primacy effect occurred because the first list items suffered less from output interference (e.g., Brown, Preece, & Hulme, 2000; Nairne 1990). Others have suggested that the first items are more activated than the remaining items in memory, leading to the primacy effect (the primacy gradient; see Page & Norris, 1998). The edge effect, according to which the first and last list items are less likely to transpose because they have fewer neighbors has also been suggested in order to account for primacy and recency (e.g., see Burgess & Hitch, 1999; see Farrell & Lewandowsky, 2002 for a review). There is still no agreement among researchers with regards to the factors responsible for shaping the serial position curve. There is a large consensus however, that the primacy and recency effects reflect one of the most important signatures of immediate memory.

Serial position curves with primacy and recency effects are not restricted to verbal material. Indeed, there are demonstrations of primacy and recency effects with a range of stimuli such as spatial locations presented visually on a computer screen (Smyth & Scholey, 1996), bursts of white noise distributed in space (Groeger, Banks, & Simpson, 2008; Parmentier & Jones, 2000), visual matrices (Avons, 1998), photographs of snowflakes (Neath & Knoedler, 1994), unfamiliar faces (Smyth et al., 2005; Ward et al.,

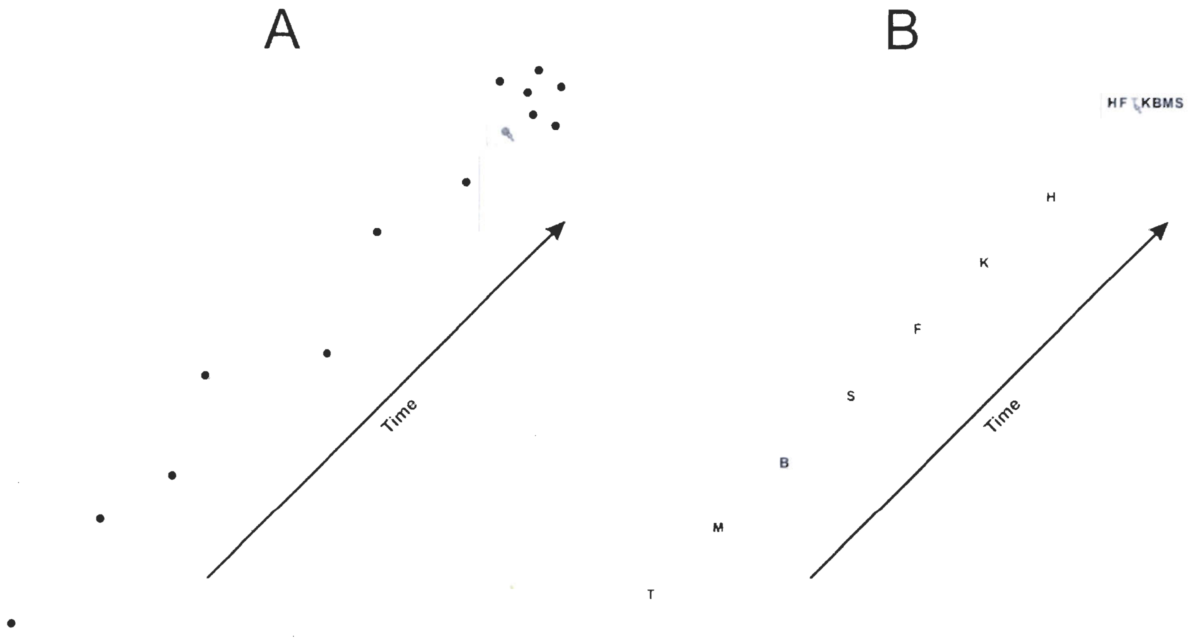

Figure 1. Schematic diagrams illustrating the presentation of seven TBR items, either a series of letters (A) or dots distributed in space (B), for the verbal and spatial versions of serial memory tasks.

2005), colored squares (Jalbert, Saint-Aubin, & Tremblay, 2008), tactile (Mahrer & Miles, 1999) and olfactory stimuli (Miles & Jenkins, 2000). In the case of the comparison between verbal and spatial information, Jones et al. (1995; see also Guérard & Tremblay, 2008; Tremblay, Parmentier et al., 2006) examined order reconstruction for dot locations and for sequences of letters (see Figure 1) within a repeated-measures design and showed similar serial position curves regardless of content, with very similar primacy and recency effects. Comparable serial position curves across domains is a first indication that similar mechanisms might come into play no matter what type of information is to be remembered.

The modality effect. When memory for visual- and auditory-verbal materials are compared directly, a stronger recency effect is found for the retention of auditory information (the so called modality effect; see e.g., Battacchi, Pelamatti, & Umilta, 1990; Crowder & Morton, 1969; Penney, 1989; Surprenant, Pitt, & Crowder, 1993). Such an

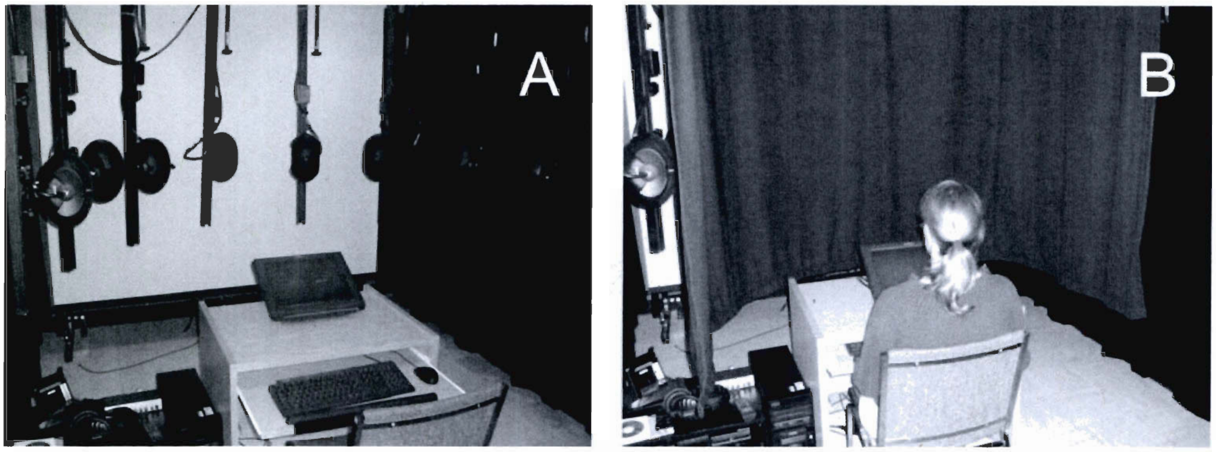

Figure 2. Photographic representations of the setup employed for testing order reconstruction of auditory-spatial information. Seven bursts of white noise were presented one at a time through seven different loudspeakers (A). A thin curtain hid the speakers in order to discourage participants from using visual cues to recode locations of the auditory stimuli (B). Loudspeakers are arranged around the participant at a radius of 1.3 m, located at – 75, -50, -25, 0, +25, +50 and +75 degrees relative to the mid-sagital plane of the participant. All stimuli were positioned at the same elevation around participants, corresponding approximately to the level of their ears.

interaction between the visual and auditory modalities has also been observed in the spatial domain (Tremblay, Parmentier, et al., 2006). These results have been obtained using an auditory-spatial version of the order reconstruction task in which participants have to recall the locations from which bursts of white noise are presented (see Figure 2). Such results suggest that the advantage for auditory information is not related to phonology, but to the acoustic properties of auditory stimuli.

Error patterns. In addition to primacy and recency effects, the type of errors and their distribution across serial positions are good indicators of the processes implicated in a memory task (see Henson, 1998). For example, transpositions – items recalled in a serial position different from that in which they were presented – and intrusions – items originating from previous lists – have been associated with confusion between similar temporal characteristics (e.g., see Brown et al., 2000; Burgess & Hitch, 1999; see Guérard & Tremblay, 2008, for a discussion) whereas omitted responses have frequently been attributed to representations with low activation in memory (e.g., see Henson, 1998; Page

& Norris, 1998). The pattern of transpositions typical of verbal serial recall – that is, the predominance of adjacent transpositions or items recalled one serial position away from that in which they had been presented (Conrad, 1964; Lee & Estes, 1977) – is also observed with sequences of spatial stimuli (Parmentier & Jones, 2000; Smyth & Scholey, 1996). A detailed analysis of errors also revealed that transpositions, intrusions as well as omitted responses are similarly distributed for verbal and spatial serial recall tasks, suggesting that similar mechanisms may underlie the production of errors regardless of content (Guérard & Tremblay, 2008; see also Cornoldi & Mammarella, 2006).

The effect of perceptual distinctiveness. Perceptual distinctiveness effects occur when an item that differs from its otherwise relatively homogenous neighbors in a list of TBR items enjoys better recall. Distinctiveness relates to a principle that has been shown to underlie memory performance and forgetting in a variety of experimental contexts (see Brown, Neath, & Chater, 2007). Most perceptual distinctiveness effects have been shown with verbal material. For example, lists of verbal items (or items that can be readily recoded verbally) for which characteristics such as color and font size are dissimilar, are better recalled than lists of items that all share the same physical characteristics (e.g., Logie, Della Sala, Wynn & Baddeley, 2000; Poirier, Saint-Aubin, Musselwhite, Mohanadas, & Mahammed, 2007; Walker, Hitch, & Duroe, 1993). Recent studies have shown that distinctiveness effects can also be found with spatial information. Jalbert et al. (2008) presented series of colored squares sequentially at different locations on the computer screen. Participants were asked to recall the spatial locations of the squares in their order of presentation. They observed that memory performance improved when items were presented using dissimilar colors compared to similar colors (see also Avons & Mason, 1999, Neath & Knoedler, 1994 and Smyth et al., 2005, for similar results with sequences of visual matrices, snowflakes and unfamiliar faces respectively). Another effect of distinctiveness is observed when a single item is made distinct from the other items in the list by isolating a unique feature (von Restorff, 1933). For example, a letter presented in a different color (Huang & Wille, 1979; Lippman & Lippman, 1978; Smith & Stearns, 1949), case (Huang & Hynum, 1970; McLaughlin, 1966), or font size (Cimbalo, Capria, Neider, & Wilkins, 1977; Kelley & Nairne, 2001; Kroll, 1972) compared to the other list items is better recalled than the corresponding item presented in an homogeneous list. The isolation effect, hitherto restricted to verbal memory tasks, has been extended to the spatial domain. Indeed, this effect is also observed when participants have to recall the order in which a series of spatially distributed dots is presented (Guérard, Hughes, & Tremblay, 2008). Guérard et al. found that when a single red dot was inserted in a sequence of black dots, recall of the red dot was enhanced compared to the correspondingly-positioned item in a sequence of all-black dots. Taken together, these studies suggest that distinctiveness is a determinant factor in immediate memory, regardless of the nature of the TBR items. The demonstration that similar principles apply to the retention of spatial and verbal information suggests that similar processes are called upon regardless of the type of TBR information.

Temporal grouping. Grouping is a phenomenon linked to perceptual organization and that has been studied extensively in the verbal domain in order to constrain existing models of immediate memory (e.g., see Ng & Mayberry, 2002, 2005). Temporal grouping effects occur when smaller groups are created within the TBR list by inserting extended pauses. For example, recall for a list of nine verbal items presented at a constant rate (ungrouped; 846319274) is compared with that for a list broken into sub-groups (grouped; 846-319-274). Such grouping has been shown to improve recall accuracy and modify the shape of the serial position curve in a way that mimics the grouping – that is, a scalloping effect showing peaks in performance corresponding to the locations of extended pauses along the serial positions (e.g., Ng & Maybery, 2002). Temporal grouping also alters the pattern of transpositions, with an increased tendency for items to transpose within rather than between their respective sub-groups, and when they do transpose between their respective sub-groups, to retain their within-group ordinal position (e.g., see Frankish, 1985, 1989; Hitch, Burgess, Towse, & Culpin, 1996; Maybery, Parmentier, & Jones, 2002). Temporal grouping effects have also been investigated in the spatial domain in order to determine whether the processes responsible for the retention of verbal and spatial information obey the same rules. When extended pauses are inserted following the third and sixth items of a series of nine dots presented sequentially on the screen, overall performance increases, the typical scalloping effect is observed and within-group transpositions increase (Parmentier, Andrés, Elford, & Jones, 2006; see also Parmentier, Maybery, & Jones, 2004). The similar temporal grouping effects observed in verbal and spatial memory tasks further suggests that the type of TBR information is not a determinant factor for explaining performance.

Hebb repetition. In the case of the Hebb repetition effect, it is the long-term learning of order information that seems to transcend domains (Couture & Tremblay, 2006; Milner, 1971; Turcotte, Gagnon, & Poirier, 2005) and extend to a range of TBR stimuli (Hay, Smyth, Hitch, & Horton, 2007; Page, Cumming, Norris, Hitch, & McNeil, 2006). In the classical Hebb procedure, one particular sequence of items is repeated every few trials across the experimental session – for example, the sequence 4-2-7-6-9-1-5 presented in that particular order is repeated every four trials. Each repetition is followed by a number of interpolated sequences in which the particular order of the items is never repeated during the course of the experiment. Even though most participants are not aware of the repetition, their performance at recalling the repeated sequence is markedly improved compared to that for interpolated non-repeated sequences. Following the original demonstration by Hebb in 1961, this effect has been replicated many times in the verbal domain (e.g., Cohen & Johansson, 1967; Cumming, Page, & Norris, 2003; Cunningham, Healy, & Williams, 1984; Melton, 1963; McKelvie, 1989). There is evidence that the Hebb repetition effect also occurs with sequences of spatial stimuli (Couture & Tremblay, 2006; Milner, 1971; Turcotte et al., 2005). When performance for the repeated sequence is analyzed throughout the course of the experiment, both the verbal and spatial versions of the procedure lead to very similar learning curves (see Couture & Tremblay, 2006). The Hebb repetition effect is assumed by many researchers to reflect the interaction between long term and immediate memory (see Page & Norris, 2009, for a discussion). Although the exact contribution of long term memory to the retention of spatial information is still unclear (Kemps, 2001; see Tremblay & Saint-Aubin, 2009, for a discussion), these results show that long-term representations can be created and support recall for both spatial and verbal material.

Cross-domain interference. The extension of classical verbal memory phenomena to the spatial domain advocates for functional equivalence between verbal and spatial information. However, one may still doubt that remembering verbal and spatial information relies on *the same* mechanisms, since equivalent but nevertheless separate components could still yield similarities (see e.g., Logie, 1995; Smyth et al., 2005). The demonstration of cross-domain interference however, provides a stronger case against modular accounts since they show that processing information from one domain can conflict with the retention of information from a different domain. For example, articulatory suppression, which is a verbal task, was shown to impair performance in a memory task involving spatial stimuli (see Jones et al., 1995; Smyth & Pelky, 1992; see also Morey & Cowan, 2004), two tasks that should, according to a modular account, rely on separate and independent memory structures. Spatial tapping has also been found to affect performance in a verbal serial recall task (e.g., Jones et al., 1995; Larsen & Baddeley, 2003; Morris, 1987). Furthermore, tapping a spatial pattern (Guérard, Jalbert, Neath, Surprenant, & Bireta, in press) or a syncopated rhythm (e.g., Larsen & Baddeley, 2003; Saito, 1993, 1994) interacts with the phonological similarity effect. The phonological similarity effect refers to the better memory performance for lists of dissimilar verbal items compared to that for lists of similar items. Although there are effects of similarity in other domains, such as the detrimental effect of visual similarity (see e.g., Avons & Mason, 1999), the *phonological* similarity effect can be considered a purely verbal phenomenon since it is concerned with phonology. The finding that spatial, or more generally, non-verbal activities interact with such a speech-based effect also questions the existence of specific modules.

Several studies also showed that there are instances of cross-domain interference from the mere presence of task irrelevant auditory stimuli. Indeed, even though participants are told to ignore such stimuli and focus on the memory task, it is well-established by now that irrelevant nonspeech stimuli such as tones and musical passages can be detrimental of verbal serial recall (e.g., Jones & Macken, 1993; Lange, 2005; LeCompte, Neely, & Wilson, 1997; Neath & Surprenant, 2001; Nittono, 1997; Tremblay, Macken, & Jones, 2001; Tremblay & Jones, 1998). Also, irrelevant speech seems to disrupt memory for visual-spatial information (Jones et al., 1995; Tremblay et al., 2001; see also Farley, Neath, Arbritton, & Surprenant, 2007). The cross-domain interference of irrelevant speech with the serial processing of visual-spatial information has also been observed in simulations of radar monitoring in the presence of irrelevant radio messages (see Banbury, Tremblay, Macken, & Jones, 2001, for a review). Importantly, the effect of irrelevant information on memory performance is not related to attentional capture or demands of attentional resources (Hughes, Vachon, & Jones, 2005). Instead, Jones, Beaman, and Macken (1996; see also Jones & Tremblay, 2000) suggested that irrelevant sounds disrupt memory for order because both irrelevant sounds and TBR items call upon common seriation processes, namely those involved in the obligatory pre-attentive organisation of the irrelevant stimuli and the voluntary processing of serial order of the TBR items.

Empirical evidence of cross-domain interference adds to the large number of studies that extended to the spatial domain several phenomena hitherto thought to be restricted to the verbal domain. For the sake of completion and synthesis, such key findings, some discussed above as well as others that have not been discussed in the present article, are presented in Table 1. These demonstrations undermine the notion of separate modules for processing different types of materials. Instead, they favor a more parsimonious approach, in which the same processes are responsible for the retention of verbal and spatial information. Of course, such an alternative is only acceptable if it can also handle the existence of behavioral dissociations between spatial and verbal information.

RECONCILING FUNCTIONAL SIMILARITIES AND DISSOCIATIONS

There are three sets of findings that would need to be accounted for by models of immediate memory: 1) the existence of double dissociations, 2) the presence of phenomena that are functionally equivalent across the verbal and spatial domains, and 3) the observation of cross-domain interference. Several theoretical views of immediate memory are now discussed in light of these critical sets of findings.

WORKING MEMORY

The WM model (Baddeley & Hitch, 1974; Baddeley, 1986, 2000) is by far the most prolific model of memory. The key premise of the WM model and of other modular accounts (e.g., see Wickens, 1992) is that immediate memory comprises specialized subsystems responsible for the processing of different types of information. Some

Table 1

List of studies reporting canonical phenomena typically associated with verbal memory and studies reporting spatial analogous effects.

	Verbal		Spatial	
Effects	Study	Type of task	Study	Type of task
Bow-shaped serial position curves	Hanley & Broadbent, 1987	serial recall	Avons, 1998	OR
	Rundus, 1971	free recall	Farrand & Jones, 1996	serial recall
	Ward et al., 2005	OR	Smyth & Scholey, 1994	OR
Order error distribution	Conrad, 1964	serial recall	Avons & Mason, 1999	OR
	Henson, 1996	serial recall	Guérard & Tremblay, 2008	OR
	Guérard & Tremblay, 2008	OR	Parmentier & Jones, 2000	OR
	Lee & Estes, 1977	free recall	Smyth & Scholey, 1996	OR
Modality effect	Battacchi et al., 1990	serial recall	Tremblay, Parmentier et al., 2006	OR
	Beaman, 2002	serial recall		
Articulatory suppression	Jones et al., 1995	OR	Jones et al., 1995	OR
	Meiser & Klauer, 1999	OR	Smyth & Pelky, 1992	OR
	Morris, 1987	serial recall		
Spatial tapping	Jones et al., 1995	OR	Meiser & Klauer, 1999	OR
	Larsen & Baddeley, 2003	serial recall	Zimmer et al., 2003	IT
Irrelevant speech	Jones et al., 1992	serial recall	Jones et al., 1995	OR
	LeCompte et al., 1997	serial recall	Tremblay et al., 2001	serial recall
	Salame & Baddeley, 1982	serial recall		
Temporal grouping	Frankish, 1985	serial recall	Parmentier et al., 2006	serial recall
	Henson et al., 2003	IT	Parmentier, Maybery, & Jones, 2004	OR
	Mayberry et al., 2002	serial recall		
Hebb repetition effect	Cohen & Johansson, 1967	IT	Couture & Tremblay, 2006	OR
	Couture & Tremblay, 2006	OR	Milner, 1971	OR
			Turcotte et al., 2005	serial recall
Sandwich effect	Baddeley et al., 1993	serial recall	Tremblay et al., 2005	OR
	Nicholls & Jones, 2002	serial recall		
Suffix effect	Balota & Engle, 1981	serial recall	Parmentier, Tremblay, & Jones, 2004	OR
	Morton et al., 1971	serial recall		
Perceptual distinctiveness effect	Huang & Wille, 1979	free recall	Avons & Mason, 1999	OR
	Kelley & Nairne, 2001	OR	Guérard et al., 2008	OR
	Logie et al., 2000	serial recall	Jalbert et al., 2008	OR

Note. These studies convey a representative portray, but are not exhaustive. OR = order reconstruction; IT = item recognition.

computational models have been proposed to further explain the functioning of the verbal subsystem, namely the phonological loop (e.g., Burgess & Hitch, 1999; Henson, 1998; Page & Norris, 1998). These models however, have not yet been extended to account for the processing of visual-spatial information.

Baddeley and Hitch (1974) suggested that spatial and verbal materials are processed by two independent specialized subsystems to account for the findings that participants could carry out two different tasks simultaneously without much interference (e.g., spatial tracking and articulatory suppression; see Baddeley, Logie, Bressi, Della Sala, & Spinnler, 1986). Double dissociations are explained within the WM model by assuming that interference is greater when two concurrent tasks employ the same type of stimuli due to their reliance on the same memory component. The WM model can also accommodate functional similarities since the verbal and spatial modules are believed to be functionally equivalent (see Logie, 1995). Indeed, if the two components operate the same way, they should produce equivalent patterns of performance.

The WM model however, has difficulties explaining cross-domain interference. Meiser and Klauer (1999) proposed that a modular approach could account for cross-domain interference by invoking the involvement of the central executive in spatial tapping and articulatory suppression as well as in verbal and spatial serial recall tasks. However, cognitive activities that do not require the central executive, such as hearing irrelevant stimuli, were shown to produce cross-domain interference (see Jones et al., 1995; Jones & Macken, 1993; LeCompte et al., 1997). Moreover, spatial tapping seems to alter the phonological similarity effect (e.g., see Guérard, Jalbert et al., in press): The phonological similarity effect however, has long been attributed to confusion at the level of the component responsible for processing verbal information – namely the phonological loop – and is believed to be independent of the action of the central executive (see, Baddeley, Lewis, & Vallar, 1984; Larsen & Baddeley, 2003). These effects question the basic principles of the WM model and can only be accounted for by supposing that any type of irrelevant information has access to the specialized subsystems, which clearly renders them no longer specialized.

Arguably, the dominance of the WM model may have had the undesirable effect of crystallizing a functional fractionation between verbal and spatial memory in researchers' minds. Indeed further fractionation is sometimes suggested in order to account for any apparent dissociation or data that undermine the initial scheme of fractionation. A good example of this is the addition of Baddeley's (2000) episodic buffer to fulfill the function of binding information of different domains to the originally tripartite model (Baddeley & Hitch, 1974). Similarly, the finding that memory for visual information (e.g., remembering faces) activates different brain regions than memory for spatial information has also led to the suggestion that the visual-spatial WM component – that is, the visuo-spatial sketch pad (see Logie, 1995) – could be further fractionated in two independent subsystems (see e.g., Courtney, Ungerleider, Keil, & Haxby, 1996; Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999; Klauer & Zhao, 2004). The adoption of the modular view has implications for experimental design as well as interpretation of results. It is possible that the observed independence between verbal and spatial stimuli is to some extent related to the selection of stimuli and tasks (see Ward, 2001, for a discussion).

The WM model (Baddeley, 1986; Baddeley & Hitch, 1974; Logie, 1995) has certainly generated considerable research and has served as reference framework in many disciplines. However, several of its basic principles have been questioned, such as the notions of activation and decay (see Nairne, 2002; Waugh & Norman, 1965), the existence of specialized memory stores (see Acheson & MacDonald, 2009; Jones et al., 2004, 2006; Miller, 2000; Nystrom et al., 2000) and the distinction between immediate memory and long term memory (see Brown et al., 2007; Crowder, 1982; Surprenant & Neath, 2008). This questioning has led to the development of new models, several of which are based on the principle of similarity.

MODELS BASED ON THE PRINCIPLE OF SIMILARITY

One could argue that rather than advocating the existence of separate memory systems functioning in a similar fashion, a more parsimonious alternative would be to assume a single mechanism common to verbal and spatial information (see, e.g., Pickering, Gathercole, & Peaker, 1998). Such a unitary concept is found in the Embedded-Processes

Model proposed by Cowan (1999; see also Cowan, 1995). In this model, the fractionation of memory is claimed not to be necessary. Rather, memory is assumed to be attention-based with representations of any form undergoing the same storing and processing operations at different levels of activation. Its operating mechanism, put forward to account for patterns of interference in memory, relies on item similarity. The very same rule of item-based similarity is at the basis of several computational models of memory, such as the Feature Model (Nairne, 1990; Neath, 1999), the scale-independent memory perception and learning model (SIMPLE; Brown et al., 2007) and the Oscillator-based associative recall model (OSCAR; Brown et al., 2000; see also Oberauer & Kliegl, 2006). The great majority of these models do not make explicit assumptions about modularity while some of them have been adapted to deal with non-verbal stimuli (see Brown et al., 2007; Oberauer & Kliegl, 2006). For example, a typical double dissociation pattern was simulated by a quantitative model based on the principle of similarity and feature overwriting (see Oberauer & Kliegl, 2006). Similarity-based models predict that two tasks will interfere with each other to the extent that they incorporate similar items, and can therefore account for double dissociations. They can also explain functional similarities since the same memory principles operate regardless of the type of information included in a memory task. The main problem with this approach is similar to that of the WM model (Baddeley, 1986): interference by similarity cannot explain cross-domain interference occurring between very dissimilar tasks, such as the effect of articulatory suppression on serial recall of visual matrices (Avons, 1998) and of that of irrelevant sounds on performance in verbal reconstruction (Jones & Macken, 1993; LeCompte et al., 1997).

Most, if not all, of the existing models and approaches to immediate memory fail to account for at least one of the three important sets of findings we identified earlier, notably the demonstration of cross-domain interference. We suggest therefore, that a novel approach should be considered in order to reconcile the existence of similarities and dissociations between the verbal and spatial domains.

THE PERCEPTUAL-GESTURAL APPROACH

One general approach that has been developed in several areas of cognitive sciences such as linguistics and philosophy is that cognition can be conceptualized as the interaction between perception and action (what is also known as embodied cognition; see Barsalou, 1999; Glenberg, 1997; Neumann, 1987, 1990; Neumann, Van der Heijden, & Allport, 1986; Van der Heijden, 1990). Such an idea has recently been applied to memory, with the premise that the co-opting of perceptual processes and of gestural systems (or skills) gives rise to a variety of apparently mnemonic phenomena (see, e.g., Crowder, 1993; Hughes, Marsh, & Jones, 2008; Jones et al., 2004, 2006; Kolers & Roediger, 1984; Macken & Jones, 2003; Wilson & Fox, 2007). This view, namely the perceptual-gestural framework (see Jones et al., 2006), is couched within a procedural approach in which memory is viewed as a series of actions rather than a collection of stores (e.g., Crowder, 1982, 1993). It also departs from the principle of activation and decay at the basis of several models of immediate memory (e.g., see Baddeley & Hitch, 1974; Burgess & Hitch, 1999; Cowan, 1999; Henson, 1998; Page & Norris, 1998). Instead, Jones et al. suggest that retention depends on the recruitment of peripheral processes such as perceptual organization and the planning of actions.

Perceptual organization. Perceptual organization is the process by which our perceptual systems organize the incoming stimuli in order to produce a coherent event (Bregman, 1990). In the visual domain, individuals tend to group items that look alike or that are proximal. Similarly, in the auditory domain, individuals attribute sounds with very different acoustic properties – e.g., different voices – to different sources (what has been called stream segregation; see Handel, 1993) and group those that share a common carrier (see also Moore, 1997). The concept of streaming according to which single auditory items are linked by pre-attentive processes, leading to the perception of an auditory stream, is particularly relevant to the perceptual-gestural view (Jones et al., 2006). TBR items that bear similar acoustic characteristics, such as items presented from the same spatial location (e.g., see Parmentier, Maybery, Huitson, & Jones, 2008) or pronounced by the same voice (see Hughes et al., 2008), tend to be assigned to the same stream due to their level of coherence. Breaking perceptual coherence leads to poor memory performance (see Goldinger, Pisoni, & Logan, 1991) and to the modulation of interference by irrelevant sounds (Jones, Alford, Bridges, Tremblay, & Macken, 1999).

The planning of action. In order to produce the various memory phenomena, the perceptual systems interact with the processes involved for planning sequences of actions. According to Jones et al. (2004), the streams formed through perceptual processes feed automatically into the planning programs in order to set up the sequence of gestures needed to reproduce the incoming sequence (what is seen as embodiment; see Neumann, 1990). These general purpose planning mechanisms are responsible for translating the incoming stimuli into a series of motor actions that will serve to impose an order to the sequence - what is traditionally seen as rehearsal. The efficacy with which the sequence of actions can be coordinated is determinant of recall performance and is thought to be the source of most errors in serial recall (e.g., see Jones et al., 2006). Rehearsal then, is seen as a way to reconstruct the sequence of items (see Jones et al., 2004, 2006) and retain their order rather than as a mechanism used for refreshing items held in a bespoke store (e.g., see Baddeley, 1986).

In the verbal domain, several authors agree that the planning of speech plays a key role in the retention of verbal information (e.g., see Acheson & MacDonald, 2009; Jones et al., 2004, 2006; Page, Madge, Cumming, & Norris, 2007; Woodward, Macken, & Jones, 2008). In verbal serial recall, performance would be modulated by the efficacy with which the sequence of items can be articulated. Indeed, if the articulatory programs are recruited as a mean to retain verbal information – either vocally or sub-vocally (e.g., Murray, 1968) – memory for long words is poorer because the assembly of motor programs required for the reproduction of such stimuli are more difficult to coordinate than those used for short words (see Woodward et al., 2008). Speech utterances for which the co-articulation between words is relatively difficult are also less well recalled than those that are easy to co-articulate (Murray & Jones, 2002; Woodward et al., 2008). There is also evidence to suggest that the phonological similarity effect is primarily the result of speech errors (cf. Spoonerisms) occurring during the motor-planning process: the elements comprising the speech motor plan are more prone to transpositions (or exchanges in the parlance of speech error research, e.g., see Acheson & MacDonald, 2009; Page et al., 2007) when they are articulatorily (not phonologically) similar (see Jones et al., 2006; Murray, 1967, 1968). Errors committed during the recall of 'phonologically' similar items bear a striking resemblance to those that can be produced spontaneously in natural speech (see Ellis, 1980; Page et al., 2007). The WM model (Baddeley, 1986) could also explain these effects in terms of articulation efficiency. The articulatory loop however, is considered to be error free and forgetting ultimately results from a loss of activation at the level of the memory representation in a separate store. The perceptual-gestural view differs since it predicts that errors occur during the planning of the articulatory movements of the sequence.

Although the retention of verbal information is well documented, less attention has been paid to the skills responsible for the retention of non-verbal material. For example, eye movements have been suggested as a vehicle for the rehearsal of visual-spatial information (Lawrence et al., 2004; Pearson & Sahraie, 2003; Tremblay, Saint-Aubin, & Jalbert, 2006). In the spatial domain, there also seem to be impairments associated with the use of eye movements during rehearsal. For example, path length – that is, the total trajectory distance between adjacent dots in a spatial sequence – is known to modulate performance (Parmentier et al., 2005, 2006; see also Smyth & Scholey, 1994). Recent findings showed that preventing eye movements during a retention interval abolished the recall advantage of short paths over long paths, placing the locus of the path length effect at rehearsal (Guérard, Tremblay, & Saint-Aubin, 2009). Since eye movements take longer to execute and are less precise when they travel over long distances than over short distances (e.g., see Abrams, Meyer, & Kornblum, 1989), one possibility is that the path length effect results from the more difficult coordination of eye movement used for spatial rehearsal in the long path condition. Therefore, path length would not somehow affect the features of the memory representations or their level of activation, but rather, would interact with the skills that are called upon in order to retain information.

The manifestation of rehearsal may appear as a distinction between the retention of spatial and verbal information in that it seems to be closely related to the nature of the TBR material. However, as argued by Macken and Jones (2003; see also Jones et al., 2004, 2006), it may be a reification to say that there are spatial and verbal memory stores just because the nature of the stimuli affords a form of rehearsal that tends to mimic the presented material. So speech is used when the TBR material is verbal not because there is a bespoke speech-based (phonological) memory store but because speech is characterized by an array of qualities and habits (e.g., its inherent sequentiality, prosody, intonation) that makes it an ideal medium for reproducing a verbal sequence. Even though articulation and eye movement are privileged means to retain verbal and spatial information, there are several ways of rehearsing one type of information. For example, finger movements can be used in order to retain verbal information (Reisberg, Rappaport, & O'Shaughnessy, 1984). The hypothesis that factors such as word length and phonological similarity affect the efficiency with which the sequence of items can be rehearsed instead of the representations held in memory leads to the prediction that using a different skill for the retention of verbal information will abolish these effects. Instead, performance reveals limitations associated with the skill used for retention. For example, Leybaert and Lechat (2001) showed that when sign language is used to retain verbal information, items represented by similar hand-shapes are more difficult to remember than items represented by different hand-shapes. Similarly, Wilson and Fox (2007) showed that sequences of gestures that are similar to each other and that take longer to execute are more poorly recalled than sequences of dissimilar and short gestures.

The source of double dissociations. Within the perceptual-gestural framework (Jones et al., 2004, 2006), selective interference would be assumed to arise when two activities performed together rely on similar skills for the retention of information and is associated with difficulties to coordinate two activities that rely on similar responses. For example, if articulation is recruited to perform articulatory suppression during verbal serial recall, performance is impaired because it is difficult – if not impossible – to coordinate the articulation of irrelevant tokens and that of the TBR items. If two tasks that must be performed concurrently rely on distinct motor actions, it is assumed less interference will occur. The level of interference between two tasks is therefore a function of the extent to which two tasks rely on similar skills (e.g., see Neumann, 1987).

The source of functional similarities. Jones et al. (2006) suggested that perceptual organization processes mostly intervene when the TBR items are presented auditorily (see also Crowder, 1971). There is evidence however, that perceptual organization also plays a role during the retention of visual information, at least in the case of visual non-verbal information (e.g., Jiang, Olson, & Chun, 2000; Woodman, Vecera, & Luck, 2003). As pointed out by Handel (1993): "the perceptual dispositions, rules and strategies that lead visual elements to be seen as one or more events must be similar to these that lead auditory elements to be heard as one or more events" (p. 185). Indeed, the perceptual processes would not depend on the content, but on the ability of our perceptual system to organize the input into a coherent event. Perhaps some types of stimuli are organized less efficiently than auditory information (such as series of visual letters presented sequentially in the center of a computer screen). For example, series of spatial locations could be organized within a visual configuration where successive objects are connected by spatial transitions. Eye movements would constitute an ideal medium for reconstructing such pattern. The same processes of perceptual organization and of action planning would nevertheless be responsible for processing any type of information (e.g., see Neumann, 1990), leading to the demonstration of functional similarities. This idea relates to the existence of supra-modal organizational principles operating for both visual and auditory information (see Aksentijevic, Elliott, & Barber, 2001)

The source of cross-domain interference. The perceptual-gestural framework provides two possible sources of cross-domain interference. Jones et al. (2006) pointed out that "the use of language skills (e.g., speech) merely constitutes a restricted example of a general strategy of co-opting motor skills to meet the demands of a short-term 'memory' task" (p. 279), suggesting that the first source of interference might be the use of general purpose planning mechanisms that operate regardless of the nature of the information. The specification of the action parameters constitute one type of general planning mechanisms that could be responsible for producing interference (e.g., see Neumann & Klotz, 1994). If participants are required to retain a list of digits, the specific arrangement of mouth shapes and tongue positions that will allow reconstructing the sequence need to be elaborated, at least in part, by retrieving information from long-term knowledge (see Neumann, 1987; see also Jones et al., 2004). The retrieval of action parameters must be carried out no matter what information is to be recalled or what skill is to be used. The recruitment of such generic motor-sequence planning processes might therefore be responsible for cross-domain interference. For instance, spatial tapping could interfere to some extent with verbal serial recall because the action parameters need to be specified for performing both tasks (e.g., see Guérard & Tremblay, 2008; Jones et al., 1995; Meiser & Klauer, 1999). Moreover, spatial tapping was found to be more disruptive for verbal serial recall when carried out during encoding than during a retention interval (e.g., Meiser & Klauer, 1999; see also Morris, 1987), perhaps because the action parameters only need to be settled once – which is most likely to be done during the encoding of the TBR list. This idea bears resemblance to late-selection theories according to which the selection of a response – or action – is a serial process that can only be achieved one response at the time (e.g., see Fagot & Pashler, 1992).

Cross-domain interference could also result from a conflict at the level of perceptual organization of the sequence (see Jones et al., 1995; Jones & Macken, 1993). For example, when irrelevant material is presented during the presentation of TBR items, there is substantial disruption of recall (e.g., see Jones & Macken, 1993; LeCompte et al., 1997). One assumption is that memory impairment occurs due to competition between similar cognitive activities (e.g., see Jones, 1993; Jones et al., 2006). Whether competition between the irrelevant stream and the sequence of TBR items results from a disruption at the level of the transitions relating successive items (e.g., see Jones et al., 1996), or from the need to inhibit the irrelevant stream and prevent it from controlling action (e.g., see Hughes et al., 2008; see also Neumann, 1996) remains to be elucidated. Such a competition would nevertheless be responsible for producing disruption that is independent of the nature of information employed in the memory and irrelevant tasks (e.g., see LeCompte et al., 1997).

CONCLUSION

Despite evidence of dissociations between verbal and spatial information processing, the interpretation that it supports the existence of independent verbal and spatial memory stores can be questioned. Evidence of functional equivalence and of cross-domain interference casts some warranted doubts on the adoption of modularity in immediate memory, at least, in the case of serial order processing. Indeed, traditional views of immediate memory, including the WM model (e.g., see Baddeley, 1986) have difficulties explaining these sets of data. Instead of providing empirical support for the modular or unitary views, efforts should now be directed at reconciling the existence of dissociations with other kinds of empirical demonstrations, such as functional similarities and cross-domain interference, in order to account for all these important findings within a single framework. One promising avenue is the perceptual-gestural view (Jones et al., 2006), according to which perceptual organizational processes and motor-skills are co-opted opportunistically to retain information as the particular material allows. Up to now, the perceptual-gestural view has found support mainly from studies using auditory information (see Hughes & Jones, 2005, for an example with visual information). Future research should therefore aim to explore if other types of information obey the same organizational principles and rules of embodiment as those applied to the processing of auditory information, which would be expected from a unitary account.

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CHAPITRE V

CONCLUSIONS

RÉSUMÉ DES RÉSULTATS

L'objectif général de la thèse est de caractériser les processus responsables de la rétention de l'information spatiale et verbale afin de déterminer si ces processus sont communs à la rétention tous les types de stimuli. Pour ce faire, la rétention de l'information verbale et spatiale a été comparée directement à l'aide d'une procédure de double dissociation et d'une analyse approfondie des erreurs commises lors de tâches de mémoire verbales et spatiales équivalentes (Chapitre II). L'analyse des erreurs est une stratégie méthodologique toute désignée afin de comparer les processus en jeu lors d'une tâche de mémoire (voir Henson, 1996, 1998). De plus, une procédure de double dissociation a été utilisée afin de vérifier comment ces processus interagissent avec l'exécution d'une activité interférente. Des activités de nature verbale et spatiale ont donc été combinées à des tâches de mémoire verbales et spatiales. Les résultats montrent une double dissociation typique où l'activité verbale affecte la rétention de l'information verbale, mais pas la rétention de l'information spatiale, alors que l'activité spatiale altère d'avantage la performance lors d'une tâche de mémoire spatiale que lors d'une tâche de mémoire verbale. Cette double dissociation entre la rétention de l'information spatiale et verbale a été démontrée dans plusieurs études (voir p. ex., Farmer et al., 1986; Logie et al., 1990; Meiser & Klauer, 1999; Salway & Logie, 1995). De plus, une analyse des erreurs indique que les patrons d'erreurs sont très similaires entre les tâches de mémoire spatiales et verbales. La distribution des erreurs est modulée de façon équivalente par l'exécution d'une activé interférente, que la tâche de mémoire soit verbale ou spatiale. Ces résultats suggèrent que les mêmes processus sont sollicités lors de la rétention, peu importe le type d'information à retenir.

Dans le Chapitre II, l'interprétation selon laquelle les processus responsables de la rétention de l'information sont communs à tous les types d'information repose sur une comparaison directe entre la production des erreurs dans des tâches de mémoire verbales et spatiales équivalentes. Bien que cette analyse permet de comparer directement le fonctionnement des mécanismes impliqués lors des tâches verbales et spatiales, elle est peu révélatrice de la nature des processus qui entrent en jeu lors de la rétention de l'information. Dans le domaine verbal, la nature de ces processus a été beaucoup étudiée et plusieurs chercheurs s'entendent sur le rôle important de la planification langagière et de l'articulation lors de la rétention de l'information (p. ex., Jones et al., 2004; Murray, 1968). Dans le domaine spatial cependant, la nature des processus responsables de la rétention de l'information a été moins étudiée. Certains chercheurs suggèrent que le mouvement oculaire joue un rôle important lors de la rétention de l'information spatiale (p. ex., Lawrence et al., 2004; Pearson & Sahraie, 2003; Tremblay et al., 2006). D'autres encore, suggèrent que l'autorépétition spatiale est basée sur le déplacement attentionnel (p. ex., Awh & Jonides, 1998, 2001; Smyth, 1996). Par exemple, Smyth montre que même si les participants doivent fixer une croix de fixation pendant toute la présentation d'une série de localisations à mémoriser, mais sont libres de déplacer leur attention, la performance n'est pas altérée comparativement à une condition dans laquelle les participants peuvent bouger les yeux.

Les résultats de la présente thèse ne permettent pas de dissocier le mouvement oculaire du déplacement de l'attention. Tout comme certains chercheurs le suggèrent (p. ex., Tremblay et al., 2006), le mouvement oculaire est vu comme étant une manifestation mesurable du déplacement attentionnel (ce qui est appelé *covert rehearsal*; Murray, 1967; Henderson, Pollatsek, & Rayner, 1989). En effet, plusieurs études montrent qu'un déplacement des yeux est obligatoirement accompagné d'un déplacement attentionnel à l'endroit visé par la saccade (p. ex., Hoffman, 1998; Hoffman & Subramaniam, 1995; Shepherd, Findlay, & Hockey, 1986). Sheliga, Riggio et Rizzolatti (1995) suggèrent même que le déplacement attentionnel est le résultat direct de la programmation d'un déplacement oculaire, que ce déplacement oculaire soit effectué ou non (voir aussi Klein, 1980). Selon cette vision, le déplacement attentionnel et le mouvement oculaire sont tous deux reliés à l'autorépétition spatiale puisque ces deux manifestations seraient le résultat des mêmes processus de planification. Un parallèle peut être fait avec l'autorépétition verbale. Lors d'une tâche de rappel sériel verbale, les participants peuvent articuler silencieusement ou vocalement les items au cours de l'autorépétition (Murray, 1967). L'autorépétition vocale est considérée comme étant le résultat des mêmes processus que ceux impliqués dans l'autorépétition silencieuse (Murray, 1967) et est souvent mesurée afin d'examiner l'autorépétition verbale (voir p. ex., Rundus, 1971; Ward & Tan, 2004). La logique sous-jacente à la mesure des mouvements oculaires est la même que celle ayant mené les chercheurs à mesurer l'articulation vocale des items: le mouvement oculaire est mesuré afin d'étudier l'autorépétition spatiale.

Afin de vérifier si les mêmes processus sont impliqués lors de la rétention de l'information verbale et spatiale, la nature des processus impliqués lors de la rétention de l'information spatiale a été examinée à l'aide d'une analyse du mouvement oculaire (Chapitre III). L'effet de longueur des sentiers – le phénomène selon lequel la performance de rappel diminue en fonction de la distance qui sépare les localisations à mémoriser (Parmentier et al., 2005) – a été étudié lors d'une tâche de mémoire spatiale où les participants doivent retenir l'ordre dans lequel des séquences de localisations avaient été présentées. La tâche de mémoire a été combinée avec une activité de suppression oculaire pendant laquelle les participants ne peuvent pas bouger les yeux aux localisations à mémoriser : la tâche de suppression consiste à suivre des yeux deux croix qui apparaissent en alternance à gauche et à droite de la fenêtre où les points sont présentés. Les résultats montrent l'effet typique de longueur des sentiers où les sentiers longs sont moins bien rappelés que les sentiers courts. De plus, l'analyse du mouvement oculaire montre que les yeux se déplacent moins efficacement lorsque la distance à parcourir entre les localisations est plus élevée comparativement à lorsque les points sont rapprochés. Lorsque le mouvement oculaire est bloqué à l'aide de la tâche de suppression oculaire, l'avantage des sentiers courts par rapport aux sentiers longs disparaît : la performance de rappel est équivalente dans les deux conditions. Ces résultats suggèrent que l'efficacité avec laquelle les yeux se déplacent entre les localisations d'une tâche de mémoire spatiale affecte la rétention de l'information spatiale.

Cette interprétation est compatible avec les résultats obtenus dans le domaine verbal. En effet, le rôle de la planification langagière dans la rétention de l'information verbale est appuyée par un nombre important d'études ayant démontré un lien entre l'efficacité avec laquelle une liste d'items verbaux est articulée et la performance de rappel (voir p. ex., Baddeley et al., 1975; Ellis & Hennelly, 1980; Murray & Jones, 2002; Schweickert & Boruff, 1986; Woodward et al., 2008). Par exemple, lors d'une tâche de mémoire verbale, les listes de mots courts et rapides à articuler sont mieux rappelés que les listes de mots longs (p. ex., Baddeley et al., 1975). Lorsque l'articulation est bloquée, l'avantage pour les mots courts disparaît, ce qui suggère que cet avantage est attribuable à l'efficacité des processus articulatoires. Il semble donc que peu importe le type d'information à mémoriser, la rétention est modulée par l'efficacité des habiletés motrices qui sont sollicités lors de la tâche de mémoire.

CADRE THÉORIQUE

Dans le Chapitre IV, une approche unitaire selon laquelle les dissociations et les similitudes entre le verbal et le spatial résultent de la coordination entre les processus perceptifs et les habiletés motrices utilisées lors de la rétention de l'information a été présentée (voir Jones et al., 2004, 2006). Selon cette approche, la performance de rappel dépend en partie des processus liés à l'organisation perceptive de la séquence. Ces processus permettent d'organiser et de regrouper les stimuli en fonction de leur similitude et de leur proximité temporelle (p. ex., Bregman, 1990). Par exemple, les stimuli qui se suivent dans le temps seraient perçus comme faisant partie d'un événement commun, dans la mesure où ils partagent suffisamment de caractéristiques pour être attribués à la même source. Ainsi, plus les stimuli sont perçus comme un ensemble cohérent, plus ils sont faciles à retenir dans l'ordre. Dans le domaine verbal, les facteurs qui affectent l'organisation perceptive ont fait l'objet de plusieurs études (voir Bregman, 1990). Par exemple, les items prononcés dans la même voix ont tendance à être regroupés et à être perçus comme un ensemble plus cohérent que des items prononcés dans plusieurs voix différentes (p. ex., Goldinger, Pisoni, & Logan, 1991). Dans le domaine spatial, les facteurs liés à l'organisation perceptive qui affectent la mémorisation n'ont pas été clairement identifiés. Un facteur potentiel est la longueur des sentiers qui relie les localisations successives à mémoriser. Dans le Chapitre III, les résultats montrent que même lorsque l'autorépétition est bloquée, le mouvement oculaire est affecté par la longueur des sentiers, ce qui suggère qu'en plus de l'autorépétition, un autre facteur contribue à l'effet de longueur des sentiers. Une hypothèse est que l'effet de longueur des sentiers résulte en partie de l'organisation perceptive plus élevée dans les sentiers courts que dans les sentiers longs. En effet, les items présentés à proximité dans un ensemble visuel tendent à être regroupés, ce qui a pour conséquence d'augmenter la performance de rappel pour ces items (voir p. ex., Dent & Smyth, 2006; Jiang, Olson, & Chun, 2000; Woodman, Vecera, & Luck, 2003). Il est donc possible que les sentiers courts soient perçus comme des ensembles plus cohérents que les sentiers longs étant donné la tendance du système perceptif à regrouper les stimuli présentés à proximité dans l'espace.

Selon l'approche de Jones et al., (2004, 2006), la performance de rappel dépend aussi des processus impliqués dans la planification du mouvement. Afin de retenir une série d'items, une séquence de mouvements doit être coordonnée afin de reconstruire les stimuli à mémoriser. Plus ces mouvements sont difficiles à coordonner, plus les items sont difficiles à retenir et conséquemment, plus la performance de rappel est faible. Cette idée est similaire à une hypothèse qui a été proposée pour rendre compte de l'autorépétition spatiale. En effet, Smyth, Pearson et Pendleton (1988; voir aussi Logie, 1995) proposent que la rétention de l'information spatiale soit supportée par des processus liés à la planification du mouvement plus généraux que ceux impliqués dans la planification du mouvement oculaire. Selon l'approche de Jones et al. cependant, ces processus génériques de planification seraient aussi impliqués dans la rétention de l'information verbale. Les processus de planification du mouvement et ceux liés à l'organisation perceptive sont indépendants du type d'information devant être retenu et seraient sollicités peu importe que l'information soit verbale ou spatiale. L'utilisation de processus communs à tous les types d'information serait responsable de produire des effets équivalents lors du rappel verbal et spatial (e.g., voir Jones et al., 1995) et des patrons d'erreurs similaires, que la tâche de mémoire soit de nature spatiale ou verbale (Chapitre II).

Bien que la planification du mouvement soit un processus générique qui est utilisé peu importe le type de matériel à mémoriser, les habiletés particulières qui entrent en jeu lors de la rétention sont souvent reliées au type d'information à retenir. Par exemple, dans le domaine verbal, l'articulation des items joue un rôle crucial dans la rétention de l'information (p. ex., Murray, 1968). Cette habileté motrice serait privilégiée lors de la rétention de l'information verbale puisqu'elle permet de reproduire les caractéristiques acoustiques des items comme des lettres, des chiffres ou des mots, mieux que n'importe qu'elle autre habileté motrice (voir Macken & Jones, 2003). La rétention de l'information verbale dépend donc de l'efficacité à articuler les items et à coordonner les mouvements articulatoires qui permettent de reproduire la séquence. Par exemple, des items ayant la même phonologie (p. ex., les lettres B, C, P, T, V) seraient plus difficiles à rappeler que des items qui sont différents (p. ex., les lettres H, M, R, F, Z), non pas à cause d'une confusion entre les traces en mémoire (voir Baddeley, 1966), mais à cause de la difficulté à coordonner les mouvements nécessaires pour reproduire des items qui se ressemblent sur le plan articulatoire.

L'articulation est une habileté toute désignée afin de retenir l'information de nature verbale, mais pourrait difficilement permettre de retenir une séquence d'items de nature spatiale, comme une série de points noirs présentés à différents endroits dans l'espace. Certains chercheurs ont suggéré que le déplacement des yeux pourrait permettre de retenir ce type d'information (p. ex., Baddeley, 1986; Tremblay et al., 2006). Par exemple, Tremblay et al. montrent que la planification du mouvement oculaire est influencée par l'ordre dans lequel les points sont présentés. Les résultats du Chapitre III semblent aussi supporter l'idée que le mouvement oculaire joue un rôle important dans la rétention de l'information spatiale, puisque l'efficacité avec laquelle les yeux sont déplacés affecte la performance de rappel. Lorsque le participant ne peut pas utiliser le mouvement oculaire comme stratégie de rétention cependant, l'avantage pour les séquences où le mouvement oculaire est facile à coordonner disparaît. Tout comme la rétention de l'information verbale, la rétention de l'information spatiale ferait donc aussi appel à une habileté spécifique qui permettrait de reproduire les caractéristiques des séquences visuelles-spatiales, comme le mouvement oculaire. Le déplacement des yeux pourrait permettre la formation de transitions spatiales qui relient les points successifs afin de préserver l'ordre dans lequel ils ont été présentés (voir p. ex., Parmentier et al., 2004).

L'utilisation d'habiletés spécifiques au type de matériel à mémoriser serait responsable de produire des doubles dissociations telles qu'observées dans le chapitre II. En effet, lorsque deux tâches effectuées en concomitance sollicitent des habiletés motrices similaires, elles sont plus difficiles à coordonner (voir Neumann, 1990). Par exemple, la suppression articulatoire affecterait la rétention d'une liste de mots parce que les processus de planification du mouvement peuvent difficilement – ou même pas du tout – coordonner l'articulation d'items non pertinents, comme les lettres *A-B-C-D*, et l'articulation des mots à mémoriser. La suppression articulatoire aurait peu d'effet sur la rétention d'une séquence de localisations spatiales cependant, parce que le système de planification du mouvement peut coordonner plus facilement les gestes requis afin d'articuler les lettres non pertinentes et le déplacement oculaire nécessaire lors de la tâche spatiale. De même, la frappe cadencée affecterait la rétention d'une séquence de localisations à cause de l'incompatibilité entre le déplacement oculaire sollicité lors de la tâche de mémoire spatiale et le déplacement manuel sollicité lors de la tâche de frappe cadencée.

Il existe certaines similitudes entre l'approche de Jones et al. (2004, 2006) et le modèle de la mémoire de travail (Baddeley, 1986; Baddeley & Hitch, 1974). Par exemple, les deux modèles font appel à des habiletés motrices spécifiques afin de retenir l'information en mémoire. De plus, la rétention de l'information dépend de l'efficacité à coordonner ces habiletés spécifiques. Malgré ces similitudes, ces modèles diffèrent par rapport à leurs postulats centraux. Selon l'approche de Jones et al. (2004, 2006), l'autorépétition permet de reconstruire la séquence afin de lui imposer une structure. En effet, les transitions entre les items successifs permettant de préserver leur ordre ne sont pas inhérentes aux stimuli dans l'environnement. Ce sont les systèmes perceptifs et moteurs qui sont responsables de former ces transitions, soit en regroupant les stimuli par les processus d'organisation perceptive, soit en coordonnant une séquence motrice qui permettra de reconstruire la séquence. La coordination des actions motrices permettrait d'établir une relation entre les items successifs sous la forme de transitions articulatoires (p. ex., lors de la rétention de listes de mots) ou spatiale (p. ex., lors de la rétention de séquences de localisations). Cette idée diffère de la mémoire de travail qui suggère que l'autorépétition permet de recirculer l'information maintenue dans un registre spécialisé. En effet, Jones et al. nient l'existence de registres spécialisés et suggèrent que la rétention dépend de processus communs à tous les types d'information. Selon une vision procédurale comme celle de Jones et al., l'existence de modules ou de composantes n'est pas nécessaire afin d'expliquer la performance dans une tâche de mémoire. Les résultats de la thèse ne permettent pas d'invalider la vision modulaire (p. ex., Baddeley & Hitch, 1974). En effet, une vision modulaire selon laquelle les modules de mémoire sont indépendants, mais équivalents, produiraient des patrons de performance équivalents ainsi que des doubles dissociations (Chapitre II). Une telle vision pourrait aussi expliquer pourquoi la rétention de l'information spatiale dépend de l'efficacité du mouvement oculaire (Chapitre III) en supposant que le mécanisme d'autorépétition de la composante visuelle-spatiale (la tablette visuo-spatiales) est basée sur le mouvement oculaire (voir p. ex., Baddeley, 1986). Cependant, la thèse permet de démontrer que le fractionnement de la mémoire n'est pas nécessaire afin d'expliquer la performance dans une tâche de mémoire et, en combinaison avec les résultats empiriques rapportés dans le Chapitre IV, suggère qu'une approche unitaire plus parcimonieuse est plus adéquate afin d'expliquer comment l'information est retenue lors d'une tâche de mémoire.

LIMITES MÉTHODOLOGIQUES

La thèse comporte un certain nombre de limites. Premièrement, le chapitre II utilise une procédure de double dissociation qui, traditionnellement, a été interprétée à la lumière d'une approche modulaire selon laquelle la mémoire est fractionnée en modules spécifiques au type d'information à retenir (Baddeley, 1986; Baddeley & Hitch, 1974). Récemment, la validité d'une telle interprétation a été questionnée (p. ex., Brown & Lamberts, 2003; Dunn & Kirsner, 2003; Plaut, 2003). En effet, des doubles dissociations peuvent être simulées par des modèles unitaires (voir Plaut, 2003; voir aussi Oberauer & Kliegl, 2006). Par exemple, Oberauer et Kliegl ont reproduit une double dissociation entre la rétention de l'information verbale et celle de l'information spatiale à l'aide d'un modèle où l'interférence est fonction de la similitude entre deux tâches effectuées en concomitance (voir aussi Brown, Neath, & Chater, 2007; Nairne, 1990; Neath, 1999). De plus, la démonstration de doubles dissociations nécessite l'utilisation de tâches qui se différencient par rapport à au moins une caractéristique, dont la nature de l'item. Dunn et Kirsner (2003) soutiennent qu'il est inévitable qu'une double dissociation survienne à partir de ces tâches. Par exemple, une telle dissociation pourrait être attribuable à l'utilisation de stratégies de rétention différentes, adaptées pour le type de stimuli à retenir et n'impliquent pas l'existence de modules spécifiques (voir p. ex., Wager & Smith, 2003). Les doubles dissociations restent néanmoins un outil précieux dans le domaine de la psychologie cognitive puisqu'elles permettent d'étudier l'interaction entre les différents processus impliqués lors de la rétention de l'information (voir Baddeley, 2003; Brown & Lamberts, 2003). Une approche de double dissociation a donc été utilisée dans le Chapitre II, non pas pour appuyer ou infirmer la vision modulaire, mais plutôt comme un outil méthodologique permettant de mieux comprendre les processus en jeu lors du traitement de l'information et leur interaction avec l'interférence.

Une deuxième limite provient du choix de stimuli utilisés et de la généralisation des résultats à d'autres types de stimuli. Dans le chapitre II, les stimuli verbaux sont des mots à basse fréquence. Une étude pilote a démontré qu'en rappel sériel, des non-mots produisent une performance plancher alors qu'en reconstruction des mots produisent une performance plafond. Des mots à basse fréquence ont donc été utilisés afin d'obtenir une performance moyenne équivalente à celle obtenue dans les tâches spatiales. Une possibilité est que l'utilisation de stimuli différents produise des patrons d'erreurs différents. De plus, des stimuli de nature spatiale ont été utilisés dans les deux chapitres empiriques. Ce choix repose sur trois raisons : 1) la plupart des doubles dissociations observées dans le domaine de la MCT sont obtenues entre le traitement de l'information verbale et le traitement de l'information spatiale (p. ex., Meiser & Klauer, 1999), 2) le principal fractionnement qui caractérise la vision modulaire prédominante dans le domaine de la mémoire est celui entre une composante de mémoire verbale et une composante de mémoire spatiale (p. ex., Baddeley & Hitch, 1974) et 3) les stimuli de nature spatiale sont plus faciles à manipuler lors du rappel sériel et de la reconstruction de l'ordre, et sont moins sujets au recodage verbal (voir p. ex., Berch, Krikorian, & Huha, 1998). Il est difficile de savoir si les patrons d'erreurs auraient été les mêmes en utilisant des matrices de cellules noires et blanches (p. ex., Avons, 1998; Avons & Mason, 1999) ou des stimuli visuels complexes (Broadbent & Broadbent, 1981; Phillips & Christie, 1977), ce qui serait attendu si les processus responsables de la rétention sont communs à tous les types de stimuli.

TRAVAUX FUTURS

Dans le domaine de la perception, les facteurs qui contribuent au regroupement ou à la segmentation des séquences d'items présentés auditivement ont fait l'objet de plusieurs recherches (voir Bregman, 1990). Des études ont permis de démontrer que certains de ces facteurs affectent la performance lors d'une tâche de mémoire où les items sont présentés auditivement (p. ex., Goldinger et al., 1991; Jones et al., 2004, 2006; Parmentier, Maybery, Huitson, & Jones, 2008). Bien que la thèse aie utilisé des stimuli visuels, les facteurs qui influencent l'organisation perceptive de ce type de stimuli n'ont pas été étudiés directement. Les travaux futurs devraient permettre d'examiner si les mêmes principes d'organisation perceptive s'appliquent au traitement d'autres types d'information comme l'information visuelle (voir p. ex., Hughes & Jones, 2005) ou gestuelle (voir p. ex., Leybaert & Lechat, 2001) et de déterminer les facteurs qui influencent l'organisation perceptive lors de la rétention de ces types d'information.

Des efforts devraient aussi être déployés afin de réconcilier les travaux qui ont été menés dans le domaine de la mémoire et ceux faits dans le domaine de la planification du mouvement. Dans le domaine verbal, plusieurs chercheurs ont établi une relation entre la rétention des items, et la production langagière (p. ex., Acheson & MacDonald, 1999; Ellis, 1980; Page et al., 2007). Par exemple, les erreurs commises lors de la production du langage normal sont très similaires aux erreurs commises lors d'une tâche de mémoire (voir p. ex., Page et al., 2007). Un tel rapprochement entre ces deux champs d'étude permet de mieux comprendre la nature des erreurs commises lors d'une tâche de mémoire. Dans le domaine spatial, de plus en plus d'études semblent supporter l'implication du mouvement oculaire lors de la rétention (p. ex., Pearson & Sahraie, 2003; Tremblay et al., 2006). Le pont entre les études portant sur le système de mouvement oculaire et celles portant sur la rétention de l'information spatiale pourrait donc permettre de mieux comprendre la rétention de l'information spatiale et la nature des erreurs commises dans une tâche de mémoire. De façon plus générale, les travaux futurs devraient s'employer à mieux définir la nature des mécanismes génériques de planification du mouvement qui sont communs à tous les types d'information.

LA RÉTENTION DE L'INFORMATION SPATIALE : DES PROCESSUS COMMUNS OU SPÉCIFIQUES?

Les résultats de la présente thèse supportent une vision unitaire selon laquelle les processus qui entrent en jeu lors de la rétention de l'information, c'est-à-dire l'organisation perceptive et la planification du mouvement, sont communs à tous les types d'information (voir Jones et al., 2004, 2006). La distinction apparente entre la rétention de l'information verbale et celle de l'information spatiale serait due en partie au fait que ces processus génériques font appel à des habiletés qui sont spécifiques, comme par exemple l'articulation lors de la rétention de l'information verbale (p. ex., Acheson & MacDonald, 2009; Murray, 1968) et le mouvement oculaire lors de la rétention de l'information spatiale (p. ex., Tremblay et al., 2006). Ces habiletés sont spécifiques dans le sens où elles sont privilégiées parce qu'elles permettent de reproduire les caractéristiques des items et d'imposer une structure à la séquence. Une habileté donnée n'est cependant pas exclusivement dédiée à la rétention d'un type d'item particulier. Par exemple, des séquences d'items verbaux peuvent être retenues à l'aide de gestes comme ceux utilisés dans le langage des signes (p. ex., Leybaert & Lechat, 2001). La performance apparaît alors modulée par des facteurs qui affectent la coordination des mouvements des mains, comme la similitude entre les gestes utilisés pour reproduire la séquence. La mémoire de travail (e.g., Baddeley, 1986) peut difficilement expliquer ce résultat sans postuler l'existence d'un autre module de mémoire spécifique à l'information retenue sous forme de gestes. Selon la vision de Jones et al. cependant, les gestes constituent une stratégie qui permet de reproduire la séquence. Selon cette perspective, les personnes malentendantes utiliseraient le langage des signes, non pas parce qu'elles possèdent une composante spécialisée permettant de retenir les items sous forme de symboles gestuels, mais plutôt parce qu'il s'agit de l'habileté qui leur permet le mieux de reproduire les caractéristiques des items à retenir. Ces personnes font néanmoins appel aux mêmes processus d'organisation perceptive et de planification du mouvement, des processus fondamentaux qui opèrent peu importe l'individu et le type d'information à traiter (voir Jones et al., 2004; Reisberg, Rappaport, & O'Shaughnessy, 1984).

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