UNIVERSITÉ DU QUÉBEC À MONTRÉAL

LES BIENFAITS DE L'ENTRAÎNEMENT ATTENTIONNEL CHEZ LES PERSONNES ÂGÉES : EXAMEN DES EFFETS DE TRANSFERT AUX TESTS NEUROPSYCHOLOGIQUES

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TEXTE EN FRANÇAIS

DSA :	Délai d'apparition du signal d'arrêt
TRGO :	Temps de réaction à la tâche Go
TRSA :	Temps de réaction au signal d'arrêt

TEXTE EN ANGLAIS

AGoRT :	Alternative Go reaction time
ASSRT :	Alternative stop-signal reaction time
GoRT :	Go reaction time
%Go :	Percentage of correct Go responses
%SS :	Percentage of inhibition responses given for the stop-signal
%NSS :	Percentage of trials completed given for the non-stop signal
PRP :	Psychological refractory period
RT :	Reaction time
SSd :	Stop-Signal delay
SSRT :	Stop-signal reaction time

RÉSUMÉ

De récentes études suggèrent que le contrôle attentionnel peut être amélioré suite à des entraînements cognitifs informatisés. Cependant, peu d'études ont montré des preuves de transfert ou de généralisation des acquis à des tâches cliniques. Les résultats rapportés dans cette thèse émanent de deux études indépendantes montrant des effets de transfert spécifiques à des tests neuropsychologiques cliniques suite à un entraînement cognitif de l'attention. Trente-quatre personnes âgées ont participé à la première étude. La moitié des participants ont complété six séances d'entraînement de l'attention divisée, alors que les autres ont été assignés à un groupe contrôle. Vingt-huit personnes âgées et 24 jeunes adultes ont participé à la deuxième étude portant sur l'entraînement de l'inhibition. Dans chaque étude, une rétroaction individualisée de la performance (feedback) était présentée aux participants. Des pré-tests et post-tests, composés de tests neuropsychologiques, ont permis de comparer l'amélioration des performances obtenues par les groupes entraînés à celle des groupes contrôles. Les résultats ont indiqué une amélioration spécifique aux tests cliniques évaluant le contrôle attentionnel. Dans la première étude, l'entraînement de l'attention divisée a amélioré les habiletés d'alternance à la condition flexibilité du test de Stroop et au tracé B du test de Traçage de pistes. Dans la seconde étude, l'entraînement de l'inhibition a montré des effets bénéfiques au test de Stroop et au test de Hayling. Ces résultats suggèrent que l'entraînement cognitif peut améliorer les fonctions attentionnelles des personnes âgées, telles que mesurées par des tests neuropsychologiques cliniques.

Mots clés : Entraînement cognitif, vieillissement, attention divisée, inhibition, tests neuropsychologiques et transfert.

CHAPITRE I
INTRODUCTION GÉNÉRALE

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Au cours du vieillissement normal, le système nerveux subit des changements notables au niveau neuroanatomique et neurophysiologique pouvant entraîner un déclin du fonctionnement cognitif (Raz, 2000; Söderlund, Nyberg, & Nilsson, 2003). Les fonctions exécutives sont parmi les premières fonctions cognitives à subir les effets négatifs du vieillissement normal (Amieva, Phillips, & Della Sala, 2003; Andrés & Van der Linden, 2000; Bherer, Belleville, & Hudon, 2004). Au lieu de considérer les fonctions exécutives comme des processus cognitifs supérieurs (ex. raisonnement), une perspective théorique récente les décrit comme représentant un ensemble de mécanismes élémentaires qui contrôlent l'exécution d'activités cognitives complexes (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000; Royal et al., 2002; Shallice, 2002; Stuss, Shallice, Alexander, & Picton, 1995). Ce contrôle exécutif permettrait ainsi la sélection, l'inhibition et la coordination des processus cognitifs impliqués, entre autres, dans la perception, la mémorisation et l'action (Salthouse & Miles, 2002).

Bien que les fonctions exécutives semblent particulièrement sensibles au vieillissement normal, les changements observés ne sont pas équivalents chez tous les individus étant donné la grande variabilité interindividuelle observée dans le vieillissement cognitif (Hutch, MacDonald, & Dixon, 2002). Qui plus est, il semble que l'efficience cognitive peut s'améliorer ou se maintenir via la stimulation cognitive, suggérant ainsi une possibilité de plasticité cognitive au cours du vieillissement. En effet, des recherches ont démontré que la performance des aînés, à certaines tâches spécifiques, peut s'améliorer considérablement suite à un entraînement cognitif en laboratoire (voir Kramer & Willis; 2002, 2003); quoique les mécanismes et facteurs en déterminant l'efficacité sont encore peu connus (Bherer et al., 2005). L'un de ces aspects à éclaircir concerne le transfert des habiletés acquises lors de l'entraînement cognitif vers un continuum de situations différant de plus en plus de l'apprentissage initial (Willis, 2001). Par exemple, l'entraînement à des tâches de partage attentionnel chez la personne âgée peut-il produire une amélioration de la performance lors d'épreuves neuropsychologiques sollicitant aussi les ressources attentionnelles ?

Afin d'en connaître davantage sur l'effet des entraînements cognitifs auprès des personnes âgées, deux études sont proposées. La première étude a pour but de vérifier si l'apprentissage acquis, suite à un entraînement de l'attention divisée en laboratoire, se généralise à des tâches neuropsychologiques sollicitant également du contrôle attentionnel. La deuxième étude a pour objectif principal d'évaluer l'efficacité d'un protocole d'entraînement cognitif ciblant un autre aspect du contrôle exécutif particulièrement sensible à l'âge, soit la capacité d'inhibition requise dans des tâches où l'on doit stopper une réponse en cours d'exécution (paradigme du signal d'arrêt). Cette recherche vérifie également si l'apprentissage acquis, durant l'entraînement de l'inhibition, se généralise à d'autres tâches sollicitant également de l'inhibition.

Améliorer les habiletés de partage attentionnel et d'inhibition des aînés s'avère important sachant qu'elles diminuent généralement avec l'avancée en âge alors qu'elles sont impliquées dans maintes activités quotidiennes, comme la conduite automobile. Par exemple, en situation d'attention divisée, les personnes âgées seraient davantage à risque de chutes et d'accidents piétonniers au moment de traverser une rue (Hauer et al., 2003; Sparrow, Bradshaw, Lamoureux, & Tirosh, 2002). En effet, plusieurs études tendent à montrer actuellement que le maintien de l'équilibre et de la posture dans la marche est affecté par l'accomplissement d'une seconde tâche cognitive (situation d'attention divisée créant de l'interférence) étant donné le déclin attentionnel associé à l'âge (Melzer, Benjuya, & Kaplanski, 2001; Rogers & Chaparro, 2004; Woollacoot & Shumway-Cook, 2002). Ainsi, le développement d'interventions efficaces visant à améliorer les fonctions cognitives des aînés apparaît fondamental, d'autant plus que la détérioration cognitive est associée à des risques de déclin fonctionnel, de placement en hébergement de soins de longue durée et de mortalité (Bell-McGinty et a., 2002; Sands et al., 2002; Yaffe et al., 2002; Yaffe, Petersen, Lindquist, Kramer, & Miller, 2006; Tomaszewski et al., 2009).

1.1. Attention divisée, entraînement cognitif et vieillissement

L'attention divisée, c'est-à-dire l'habileté à partager son attention entre deux ou plusieurs tâches, est l'un des processus exécutifs particulièrement affecté par le vieillissement normal (Holtzer, Stern, & Rakitin, 2005; Verhaeghen & Cerella, 2002). Cette détérioration des capacités d'attention partagée avec l'avancée en âge est attribuée, entre autres, à une moindre efficacité du contrôle exécutif ou des différents mécanismes élémentaires qui gouvernent l'action (Hartley, 1992; McDowd & Shaw, 2000). Pour mesurer cet effet, les participants entreprennent habituellement deux tâches effectuées séparément (tâche simple) et en combinaison (tâche double). La performance obtenue en tâche simple est ensuite comparée à celle de la tâche double afin de vérifier si cette dernière provoque de l'interférence (ex : augmentation du temps de réponse et du nombre d'erreurs). Cette réduction de la performance en tâche double est généralement plus prononcée chez les personnes âgées comparativement à celle des jeunes adultes.

Des études d'entraînement en double tâche ont toutefois démontré que le contrôle attentionnel peut être amélioré chez les aînés. Par exemple, selon les résultats d'études réalisées par Kramer et al. (1995, 1999), l'entraînement cognitif en laboratoire aiderait les personnes âgées à mieux coordonner l'exécution de tâches concurrentes. Dans l'une de ces études, l'entraînement impliquait la coordination de deux tâches. Dans la première, les participants devaient surveiller six jauges en mouvement et les réinitialiser lors de l'atteinte d'une région critique. Dans la seconde tâche, ils devaient résoudre des équations alphanumériques (i.e., K-3 = ?). L'une des particularités de cet entraînement consistait à offrir aux participants une rétroaction continue (feedback) sur la vitesse et l'exactitude des réponses. Les résultats de Kramer et al. (1995, 1999) ont montré une plus grande amélioration des habiletés de partage attentionnel chez les aînés que chez les jeunes adultes. Les études de Kramer et al. ont suscité beaucoup d'intérêt parmi les chercheurs intéressés aux effets de l'entraînement cognitif chez les personnes âgées. Toutefois, la complexité des procédures et des tâches utilisées ne permet pas de connaître quels sont les mécanismes cognitifs qui s'améliorent après l'entraînement. Par exemple, est-ce que les participants parviennent à mieux alterner rapidement leur attention entre deux tâches concurrentes ou à mieux garder en mémoire toutes les alternatives de réponses utiles pour les tâches en cours ? De plus, les études de Kramer et al. n'ont pas évalué la généralisation des apprentissages à des tests cliniques, ce qui aurait permis de mieux connaître la nature des apprentissages supportant l'amélioration en tâche double.

Plus récemment, une série d'études de Bherer et al. (2005, 2008) a permis de mieux comprendre la nature des mécanismes qui s'améliorent après l'entraînement en tâche double. Dans ces études, les participants devaient effectuer deux tâches concurrentes aisées, soit une tâche de discrimination auditive (indiquer via une touche si un son est aigu ou grave) et une tâche de discrimination visuelle (indiquer via une touche si la lettre affichée à l'écran est B ou C). Il s'agissait donc d'une tâche auditivo-motrice combinée à une tâche visuo-motrice. Un histogramme, comprenant deux barres, affichait à l'écran la vitesse de réponse du participant à chacune des tâches afin qu'il puisse ajuster sa performance en fonction de cette rétroaction (feedback). Les barres étaient rouges initialement, mais devenaient jaunes et ensuite vertes à mesure que la vitesse de réponse augmentait par rapport à un critère de performance exigé. Ce critère, ignoré par le participant, était fixé en fonction de la performance obtenue lorsque les tâches étaient effectuées séparément. Ainsi, plus le participant devenait rapide en tâche simple, plus il devait répondre rapidement en tâche double. Les résultats ont révélé une amélioration de l'exactitude des réponses plus importante chez les aînés comparativement aux jeunes adultes, ainsi qu'une diminution équivalente du temps de réaction entre ces deux groupes. Soulignons qu'aucune amélioration n'a été observée chez le groupe contrôle de personnes âgées qui n'a pas participé aux séances d'entraînement. Cette diminution de l'écart de performances des personnes âgées par rapport à celles des jeunes adultes, suite à un entraînement cognitif intensif, est particulièrement intéressante car les tâches entreprises concurremment exigeaient des réponses motrices similaires alors que cette situation contribue à élargir la différence entre les jeunes et les aînés selon Hartley (2001). Qui plus est, le bénéfice s'est même généralisé à de nouvelles tâches expérimentales non entraînées. Ces tâches, semblables à celles utilisées durant l'entraînement, ont permis de vérifier le transfert intra-modalité (combinaison d'une tâche auditivo-motrice où le participant doit déterminer si le son est saccadé ou continu et d'une tâche visuo-motrice exigeant l'identification d'un chiffre) et le transfert inter-modalité (combinaison de deux tâches visuo-motrices; identifier un chiffre ou discriminer deux patrons visuels).

Ball et al. (2002) ont également vérifié l'effet d'un entraînement cognitif visant plus spécifiquement l'amélioration de la vitesse de traitement, mais créé dans un format d'attention divisée (voir aussi Edwards et al. 2002, 2005). Les participants devaient identifier et localiser rapidement des stimuli visuels présentés à l'écran. L'une des stratégies utilisées pour favoriser l'amélioration de la performance consistait à augmenter le niveau de difficulté de l'entraînement informatique à chaque fois que le participant atteignait un critère de performance. Le niveau de difficulté était donc manipulé en diminuant la durée des stimuli, en ajoutant des distracteurs visuels ou auditifs, en augmentant le nombre de tâches à accomplir en concurrence et en présentant les cibles dans un espace spatial plus vaste. L'entraînement a permis aux personnes âgées d'améliorer significativement leur habilité à chercher et localiser rapidement des cibles visuelles présentées simultanément.

Les études portant sur l'entraînement de l'attention divisée ont donc montré que les personnes âgées peuvent augmenter leur performance en double tâche. Cette amélioration semble d'ailleurs accentuée lorsque l'entraînement implique une rétroaction individualisée (feedback) qui permet au participant d'ajuster sa performance en fonction des consignes de la tâche, tout en le poussant à atteindre des niveaux de difficulté plus élevés. Étant donné que l'autorégulation du contrôle exécutif semble diminuer avec l'âge (Dunlosky, Kubat-Silman, & Hertzog, 2003), la présence d'une rétroaction pendant une tâche pourrait donc aider les personnes âgées à mieux ajuster leur performance et favoriser le développement de stratégies plus efficientes dans la coordination des tâches concurrentes. Le contrôle attentionnel en serait ainsi optimisé.

Les effets positifs obtenus lors des études d'entraînement cognitif démontrent qu'il s'agit d'un moyen efficient d'augmenter le contrôle attentionnel des personnes âgées. Cependant, l'effet de généralisation de cet apprentissage sur des situations non entraînées s'avère peu documenté. En fait, peu d'études ont montré des preuves d'effets de transfert suite à un entraînement cognitif et celles qui ont montré une généralisation des acquis ont utilisé des tâches fort similaires à celles complétées pendant l'entraînement (e.g. Bherer et al., 2005, Kramer et al. 1995, 1999).

Ball et al. (2002) ont toutefois vérifié si l'effet d'un entraînement de la vitesse de traitement, sous un format d'attention divisée, se généralise à des tâches similaires, mais aussi à des tâches reliées au fonctionnement quotidien. Les résultats ont révélé une amélioration de la performance touchant uniquement les tâches similaires à l'entraînement. Mentionnons toutefois que Edwards et al. (2002, 2005) ainsi que Roenker, Cissell, Ball, Wadley, et Edwards (2003) ont utilisé le même type d'entraînement que Ball et al. (2002) et ont obtenu un transfert des acquis à des mesures de vitesse reliées au fonctionnement quotidien, comme le *Timed Instrumental Activities of Daily Living* (tâches en laboratoire chronométrées), *le Road Sign Test* (test informatisé) et le *on-the-road driving performance* (évaluation de la conduite automobile sur un parcours d'environ 11 km en situation réelle). Edwards et al. (2002, 2005) ont aussi voulu vérifier l'étendue du transfert à l'aide de tests cliniques (Test de Stroop, Traçage de pistes, Substitution, Empan numérique et Empan spatial), suite à un entraînement cognitif similaire à celui utilisé par Ball et al. (2002). Leurs résultats n'ont montré aucun effet de transfert aux tests cliniques après l'entraînement.

L'absence de généralisation à des tests neuropsychologiques, suite à un entraînement de la vitesse de traitement, peut s'expliquer par le fait que ces épreuves sont sans doute plus sensibles aux changements relatifs aux fonctions attentionnelles qu'à la vitesse de performance. Selon Brenes (2002), un entraînement cognitif peut se transférer à de nouvelles tâches ciblant les mêmes fonctions cognitives (voir aussi Dahlin, Nyberg, Bäckman, & Stigsdotter Neely, 2008 et Thorndike & Woodworth, 1901). Pour obtenir une généralisation des acquis suite à un entraînement cognitif, les tâches de transfert devraient requérir la contribution des fonctions cognitives ciblées par l'entraînement. Il faudrait ainsi entraîner les mécanismes sollicités par les tâches de transfert pour obtenir une généralisation des acquis suite à un entraînement cognitif. Selon cet argument, l'entraînement en double tâche devrait améliorer les mécanismes supportant l'attention divisée. On peut donc supposer que l'entraînement permettrait une réduction de l'interférence entre des tâches concurrentes, ainsi qu'une augmentation de l'habileté à alterner entre les tâches.

Les résultats obtenus par Bherer et al. (2005) appuient cette dernière hypothèse. En effet, leur entraînement en attention divisée a amélioré les résultats à deux mesures associées aux mécanismes de contrôle attentionnel impliqués en situation de tâche double, soit le coût situationnel (task-set cost) et le coût de coordination (dual-task cost). Le coût situationnel désigne un coût global de la performance observé lorsqu'une tâche simple est entreprise parmi des essais doubles comparativement à lorsqu'elle est effectuée dans un bloc pur (sans essais doubles imbriqués aux essais simples). Ce coût situationnel refléterait la capacité à maintenir les diverses associations entre les stimuli et les réponses des deux tâches en mémoire de travail. Le coût situationnel reflète donc la charge cognitive imposée par la situation d'attention divisée sans que le sujet ait à produire deux réponses simultanément. Quant au coût de coordination, il réfère au coût de performance associé à la production simultanée de deux réponses. Le coût de coordination est mesuré en comparant la performance d'une seule tâche, lorsqu'elle est complétée seule dans les essais imbriqués aux essais doubles, à celle obtenue lors de l'exécution simultanée des deux tâches concurrentes. Les deux coûts reflètent des aspects différents mais complémentaires de la performance en tâche double. Améliorer le coût situationnel devrait réduire les ressources requises pour accomplir la double tâche et ainsi diminuer l'interférence, alors que l'amélioration du coût de la coordination serait liée à l'acquisition d'une meilleure coordination ou alternance entre les tâches.

La dissociation des bénéfices de l'entraînement sur ces différents coûts attentionnels a permis à Bherer et al. (2005) de montrer que l'entraînement améliore les mécanismes supportant le maintien des alternatives de réponses en mémoire et l'alternance entre les tâches. Ces deux types de mécanismes, essentiels à l'accomplissement de tâches concurrentes, sont donc susceptibles de s'améliorer même chez les aînés. Ainsi, on pourrait espérer que l'entraînement en double tâche leur permettrait de mieux répondre dans diverses situations d'attention divisée. C'est ce que suggèrent les effets de transfert rapportés dans une étude récente d'entraînement en double tâche de Bherer et al. (2008) dans laquelle les participants jeunes et aînés améliorent leur performance, alors que des réponses motrices similaires étaient requises pour l'exécution des deux tâches concurrentes dont la modalité de présentation était visuelle (tâches visuo-motrices). L'apprentissage acquis via l'entraînement s'est généralisé à de nouvelles combinaisons de tâches doubles non entraînées dont la modalité de présentation différait de l'entraînement (tâches auditivo-motrices). Toutefois, ces tâches expérimentales étaient accomplies sur ordinateur et étaient similaires aux tâches utilisées lors de l'entraînement. Bherer et al. (2005, 2008) n'ont pas vérifié si l'entraînement en double tâche permet d'améliorer la performance à des tâches neuropsychologiques utilisées en clinique pour évaluer les capacités attentionnelles, ce qui permettrait d'étudier davantage l'impact de l'entraînement sur la généralisation des acquis. De plus, l'étude des effets de transfert aux tests neuropsychologiques permettrait d'apprécier la valeur ou l'utilité clinique des programmes d'entraînement attentionnel.

1.2. Objectifs de l'étude 1

L'objectif de la première étude est de vérifier si l'impact d'un entraînement cognitif en double tâche, semblable à celui de Bherer et al. (2005, 2008), se généralise à des tâches neuropsychologiques sollicitant le contrôle attentionnel. Ces différents tests neuropsychologiques (Substitution, Test de Stroop, Traçage de pistes A et B, Recherche de symboles et Séquences lettres-chiffres) sont employés en clinique, entre autres, pour leur capacité à mettre en évidence des déficits attentionnels. Ces tests ont été choisis afin de cibler l'attention divisée, la flexibilité attentionnelle et d'autres aspects du contrôle de l'attention. Ces tâches cliniques diffèrent de l'entraînement sélectionné car il s'agit d'épreuves neuropsychologiques non informatisées. Nous émettons l'hypothèse que l'entraînement en double tâche se généralisera davantage au niveau des tâches partageant les mêmes mécanismes qui permettent la division de l'attention ou les capacités d'alternance (switching), comme la condition flexibilité du Test de Stroop et la partie B du Traçage de pistes. Les tâches exigeant de la vitesse psychomotrice (ex : Substitution) devraient également être avantagées par rapport aux autres puisque notre entraînement pousse les participants à augmenter leur vitesse de performance.

1.3. Inhibition, entraînement cognitif et vieillissement

L'inhibition est un autre mécanisme cognitif très sensible à l'âge pour lequel il existe peu d'étude de protocole d'entraînement cognitif. Les définitions du concept d'inhibition diffèrent selon les tâches permettant de l'étudier. En général, on le décrit comme une capacité à inhiber ou ignorer l'information non pertinente à la réalisation d'une tâche (Lemercier, Ansiau, Massioui, & Marquié, 2003). Selon certaines études, les capacités d'inhibition diminuent avec l'avancée en âge, alors qu'elles semblent préservées lorsque mesurées via d'autres tâches (pour une revue, voir Kramer & Madden, 2008 et McDowd & Shaw, 2000). Par exemple, plusieurs études n'ont observé aucune différence d'âge lorsque les habiletés d'inhibition sont mesurées à l'aide du paradigme d'amorçage négatif (Connelly & Hasher, 1993; Kramer, Humphrey, Larish, Logan, & Strayer, 1994; Schooler, Neumann, Caplan, & Roberts, 1997; Sullivan & Faust, 1993), alors que la performance des jeunes adultes est généralement supérieure à celle des aînés à la tâche de Stroop, au test de Hayling et à la tâche du signal d'arrêt (Andrés, Guerrini, Phillips, & Perfect, 2008; Andrés & Van der Linden, 2000; Bedard et al., 2002; Belleville, Rouleau, & Van der Linden, 2006; Burgess & Shallice, 1996; Collette et al., 2001; Kramer et al., 1994; May & Hasher, 1998; Rush, Barch, & Braver, 2006). La divergence des résultats obtenus a permis d'émettre l'hypothèse qu'il existe plusieurs mécanismes d'inhibition (Andrés et al., 2008; Friendman & Miyake, 2004; Kok, 1999; Kramer et al., 1994; Maylor, Schlaghecken, & Watson, 2005; McCrae & Abrams, 2001; Nigg, 2000; Rush, Barch, & Braver, 2006; Sweeney, Rosano, Berman, & Luna, 2001). Les tâches d'inhibition liées à une forme de contrôle exécutif volontaire (effort conscient et intentionnel) et associées à l'intégrité des fonctions frontales et préfrontales du cortex cérébral seraient davantage affectées par le vieillissement que les tâches d'inhibition automatique (Andrés et al., 2008; Bherer, Belleville, & Hudon, 2004; Davidson, Zacks, & Williams, 2003; Kramer et al., 1994).

La tâche du signal d'arrêt (Stop-Signal task) est souvent employée pour mesurer le contrôle volontaire de l'inhibition (ou inhibition contrôlée), entre autres, dans les recherches portant sur le déficit d'inhibition chez les enfants hyperactifs et dans quelques études auprès des aînés. Il s'agit d'une tâche où le participant doit stopper l'activité planifiée ou en cours (action ou pensée) lorsqu'un signal (ex : un son) survient au hasard. Des situations similaires surviennent fréquemment dans la vie quotidienne lorsqu'une action doit être interrompue soudainement; notamment dans le cas de la conduite automobile. Le type d'inhibition requis pour accomplir la tâche est conceptualisé comme l'un des mécanismes du système de control exécutif qui régulerait les opérations du traitement de l'information et qui permettrait l'autorégulation (Bedard et al., 2002).

En général, les expériences du signal d'arrêt impliquent une tâche de temps de réaction aux choix, nommée « tâche Go ». Par exemple, le participant doit appuyer sur une touche lorsqu'un « X » apparaît à l'écran ou sur une autre touche s'il s'agit d'un « O ». Par contre, si un son survient, il doit inhiber ou stopper sa réponse, c'est-à-dire ne pas appuyer sur la touche correspondant au stimulus apparu à l'écran. Habituellement, ce signal d'arrêt survient seulement pour 25% des essais. Dans le paradigme du signal d'arrêt, le délai écoulé entre l'apparition du stimulus « Go » et l'apparition du signal d'arrêt est généralement manipulé. Inhiber la réponse s'avère plus difficile lorsque le délai d'apparition du signal d'arrêt est long puisque le participant est sur le point de produire sa réponse, comparativement à lorsque le signal d'arrêt survient en même temps que le stimulus « Go ». Le délai d'apparition du signal d'arrêt est souvent fixé à 250ms initialement. Si le participant réussi à inhiber sa réponse, l'ordinateur augmente automatiquement le délai de 50ms au prochain essai avec signal d'arrêt (ex : 300ms) afin de rendre la tâche plus difficile. Si le participant n'a pas réussi à inhiber sa réponse (il a effectué la tâche « Go » malgré la présence d'un signal d'arrêt), le délai diminue alors de 50ms (ex : 250ms) au prochain essai avec signal d'arrêt afin de faciliter la tâche. Cette procédure nommée système de « tracking » assure un taux de réussite de 50% selon la documentation scientifique (Logan, 1994) et permet d'atteindre un point d'égalité entre le processus « go » et le processus « stop » qui sont respectivement responsables de la production et de l'arrêt de la réponse. Cette manipulation expérimentale permet alors de calculer la vitesse d'inhibition, c'est-à-dire le temps de réaction au signal d'arrêt (TRSA). Le TRSA provient de la soustraction de la moyenne des délais d'apparition du signal d'arrêt (DSA) de la moyenne des temps de réaction à la tâche Go (TRGO)[1].

À notre connaissance, les études qui ont utilisé la tâche du signal d'arrêt ont généralement observé un ralentissement du temps de réaction au signal d'arrêt (TRSA) chez les aînés en santé comparativement aux jeunes adultes, bien que les différences sont parfois modestes (Kramer, Humphrey, Larish, Logan, & Strayer, 1994; Rush, Barch, & Braver, 2006; May & Hasher, 1998; Andrés, Guerrini, Phillips, & Perfect, 2008, Keys, 2002) ou absentes (Williams, Ponesse, Schachar, Logan, & Tannock, 1999). Bedard et al. (2002) ont

[1] TRSA = TRGO - DSA

cependant observé un ralentissement plus prononcé du TRSA avec l'avancement en âge. Ils ont utilisé une version modifiée de la tâche du signal d'arrêt habituelle afin d'étudier le contrôle de l'inhibition sélective. Les participants devaient entreprendre une tâche de temps de réaction aux choix (appuyer rapidement sur une touche lorsqu'un X apparaît à l'écran et sur une autre touche s'il s'agit d'un O) et stopper leur réponse quand un son aigu survenait pour 20% des essais. Le signal d'arrêt était sélectif car un son grave, que les participants devaient ignorer, survenait aussi pour 20% des essais; obligeant ainsi une discrimination entre les sons.

Cette tâche d'inhibition sélective est plus exigeante cognitivement selon Bedard et al. (2002) mais semble plus écologique que la tâche du signal d'arrêt classique qui demande aux participants de cesser toute action dès qu'un signal d'arrêt survient. En effet, dans la vie de tous les jours, les situations qui requièrent un arrêt de l'action planifiée, suite à un signal quelconque, impliquent rarement un arrêt complet pour tous les stimuli. La conduite automobile en est un bon exemple car un signal d'arrêt peut survenir alors que l'individu se trouve dans une situation d'attention divisée où stopper tout mouvement pourrait s'avérer inapproprié. Par exemple, l'immobilisation de la voiture est requise à un feu rouge et non à un feu vert.

Une importante question à élucider, selon Kramer, Humphrey, Larish, Logan, et Strayer (1994), est de vérifier si les déficits des aînés aux tâches d'inhibition associées aux fonctions exécutives peuvent être réduits par l'entraînement cognitif. Soulignons que les études auprès des aînés mesurant l'impact de la pratique sur des tâches d'inhibition associées aux fonctions exécutives sont rares mais qu'elles révèlent une amélioration proportionnellement équivalente à celle des jeunes adultes (voir Davidson, Zacks, & Williams, 2003 ainsi que Dulaney & Rogers, 1994 pour se renseigner sur l'effet de pratique au test de Stroop). Toutefois, ces études n'ont pas utilisé de programme d'entraînement cognitif comme tel, car le participant ne faisait que pratiquer de façon répétitive les tâches sans recevoir de rétroaction ou de consignes particulières visant à moduler et améliorer ses performances. Comme nous l'avons vu dans les études sur l'entraînement en attention divisée, ce type de procédure est essentiel pour observer des effets d'entraînement significatifs.

1.4. Objectifs de l'étude 2

L'objectif de la seconde étude est de développer un programme d'entraînement cognitif de l'inhibition à partir des principes qui ont montré leur efficacité dans les études d'entraînement en tâche double. L'entraînement de l'inhibition est effectué à l'aide d'un paradigme du signal d'arrêt. Il est alors possible de vérifier si un entraînement cognitif intensif permet d'améliorer le contrôle de l'inhibition des aînés, mesuré par une diminution du temps de réaction au signal d'arrêt. D'autre part, l'utilisation de tests neuropsychologiques en pré-test et post-test (test de Stroop et test de Hayling) permet de vérifier si un entraînement au signal d'arrêt favorise l'amélioration de la performance à des tâches cliniques sollicitant également le contrôle de l'inhibition. Un déclin de la performance a été observé avec l'avancée en âge tant à la tâche du signal d'arrêt, au test de Hayling et au test de Stroop; des tests qui solliciteraient des processus d'inhibition supportés par les régions frontales du cortex cérébral (Andrés, Guerrini, Phillips, & Perfect, 2008; Andrés & Van der Linden, 2000; Bedard et al., 2002; Belleville, Rouleau, & Van der Linden, 2006; Bielak, Mansueti, Strauss, & Dixon, 2006; Burgess & Shallice, 1996; Collette et al., 2001; Collette, Schmidt, Scherrer, Adam, & Salmon, 2007; Kramer, Humphrey, Larish, Logan, & Strayer, 1994; May & Hasher, 1998; Rush, Barch, & Braver, 2006; Williams, Ponesse, Schachar, Logan, & Tannock, 1999). De plus, ces trois épreuves ont pour objectif de cesser volontairement une réponse automatique devenue inappropriée, ce qui semble correspondre à la fonction « restriction » de la théorie du déficit d'inhibition (Hasher, & Zacks, 1988; Lustig, Hasher, & Zacks, 2007). Selon cette théorie, trois fonctions d'inhibition sont proposées; l'accès, l'effacement et la restriction. La fonction d'accès empêche l'information inappropriée d'accéder au foyer attentionnel, la fonction d'effacement élimine les informations inappropriées qui sont parvenues à accéder au foyer attentionnel et à la mémoire de travail alors que la fonction restriction supprime les réponses puissantes ou automatiques devenues inappropriées en fonction du contexte. Ainsi, si le paradigme du signal d'arrêt se révèle efficace pour améliorer les processus d'inhibition via un entraînement cognitif, une amélioration devrait également être observée au test de Stroop et au test de Hayling puisque ces tests semblent partager des processus d'inhibition communs.

Une rétroaction individualisée (feedback) est présente durant l'entraînement de l'inhibition. Cette rétroaction de la performance devrait favoriser le transfert des habiletés acquises durant l'entraînement, via un mécanisme d'autorégulation, en permettant au participant d'apprendre à ajuster sa performance et ainsi favoriser un meilleur contrôle attentionnel et le développement de stratégies optimales. Par ailleurs, les pré-tests et post-tests permettent de comparer l'amélioration obtenue par les groupes entraînés à celle des groupes contrôles.

CHAPITRE II

ARTICLE 1

Improvement in clinical neuropsychological tests after dual-task training in older adults

Improvement in Clinical Neuropsychological Tests After Dual-Task Training in Older Adults

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Abstract

Recent studies suggest that attentional control can be improved in older adults after cognitive training. However, few studies have shown convincing evidence of transfer effects to untrained tasks and/or clinical tests. The aim of this study was to evaluate whether a dual-task cognitive training program, that has shown significant improvement in divided-attention in older adults (Bherer et al., 2005), can lead to transfer effects in neuropsychological tests used to assess attention and executive control functions. Thirty-four older adults participated in this study. Half of the participants completed a dual-task training program, while the others were assigned to a control group. Generalization of training effects was assessed with neuropsychological tests of attention and processing speed. The results indicated a significant improvement in divided-attention after training and significant transfer effects in neuropsychological tests. Moreover, transfer effects in clinical tests were specific to the test condition that put higher demand on attentional control, even after controlling for baseline performance. It thus seems that laboratory-based dual-task training can significantly improve attentional control in older adults and that learning generalizes to untrained clinical neuropsychological tests.

Keywords: Aging, Cognitive training, Divided-attention, Transfer effects, Neuropsychological tests

Word count for the main text = 8, 061 words (26 pages)

Improvement in Clinical Neuropsychological Tests After Dual-Task Training in Older Adults

Many studies suggest that when people grow older they tend to experience deficits in executive control and attentional functions (Kramer & Madden, 2008). However, over the last few years, cognitive training studies have demonstrated that attentional control can be improved in older adults using computerized training programs. For example, Kramer, Larish, and Strayer (1995) and Kramer, Larish, Weber, and Bardell (1999) showed that dual-task cognitive training seemed to help older adults to better coordinate the execution of multiple concurrent tasks. In Kramer et al. (1995) study, participants learned to coordinate a monitoring task (e.g., supervising six moving gauges and resetting them when it reached a critical region) and an alphabet-arithmetic task (e.g., resolve K-3 = ?). The training procedure that leads to the larger improvement in performance required for the participants to vary the priority devoted to one of the two tasks (variable-priority condition) as opposed to a more typical dual-task instruction of paying equal attention to both tasks (fixed-priority condition). Continuous feedback helped participants to adjust their performances (reaction time and accuracy) in both task according to the priority instruction. The results from Kramer et al. (1995, 1999) indicated that both older and younger adults could learn to effectively coordinate the execution of two tasks. However, a larger improvement was observed in older adults compared to younger adults. Moreover, the skills learned during training transferred to an untrained dual-task situation and were retained for up to two months (45-60 days).

Using a different task paradigm, Ball et al. (2002) also studied the effect of cognitive training with a task that aimed at improving processing speed and that also involved dividing attention (see also Edwards et al., 2002, 2005). The participants had to rapidly identify and localize visual stimuli presented in different locations in the visual field. One of the strategies used to improve performances consisted in increasing the level of difficulty of the training each time the participant reached a response criterion. The level of difficulty was manipulated by reducing the duration of stimuli presentation, by adding visual or audio distracters, by increasing the number of concurrent tasks and by presenting stimuli further apart in the visual field. Ball et al. (2002) observed that this training program significantly improved older adults' capacity to rapidly search and localize visual targets that were presented simultaneously in different regions of the visual field. These results, along with those from Kramer et al. (1995, 1999), suggest that dual-task training can help improving attentional control in older adults and that improvement occur when the training regiment involves individualized feedback allowing the participant to adjust its performance according to the task's instructions, and when task conditions encourage participant to strive for higher level of performance. The presence of a feedback indicator to promote the development of efficient coordination strategies could be peculiarly important in older adults, since self-regulation of executive control processes declines with age (Dunlosky, Kubat-Silman, & Hertzog, 2003).

Improvement in dual-task performance in older adults is of major importance in the study of age-related cognitive decline since older adults' deficit in dual-task situation has often been reported (Hartley, 1992; Kramer & Larish, 1996; McDowd & Shaw, 2000, see Verhaeghen, Steitz, Sliwinski, & Cerella, 2003 for a meta-analysis). However, many dual-task paradigms are complex and involved a variety of perceptual, memory and motor processes, and do not allow localizing the source of improvement in dual-task performance. In fact, improvement can be due to enhanced ability to resolve interference between upcoming stimuli, increased ability to synchronize concurrent output or to improvement in task switching abilities. Indeed, Kramer, Hahn, and Gopher (1999) have shown that the age-related deficit in switching between two non-concurrent tasks decreases substantially with practice. In an effort to better isolate interference between concurrent tasks, researchers have often used a combination of simple tasks (e.g., identifying a letter and discriminating between a high or a low tone), as in the Psychological Refractory Period (PRP) paradigm. In a typical PRP task, the delay between the two reaction time tasks varies. This method allows to assess the extent to which the modality of stimulus presentation (input interference), the cognitive processes employed during task performance (central interference), and/or the response processes (output interference) interfere with one another. PRP studies conducted with older adults (Allen, Lien, Murphy, Sanders, & McCann, 2002; Allen, Smith, Vires-Collins, & Sperry, 1998; Glass et al., 2000; Hartley, 2001; Hartley & Little, 1999) showed larger deficits in older compared to younger adults when the two tasks required manual responses (see also Hartley, 2001), suggesting an age-related deficit in the response generation processes, though exceptions have been reported (Allen et al., 2002). More recently, Hein and Schubert (2004) also reported increased susceptibility to input interference in dual-tasks in older adults and concluded that parallel processing at the input stage requires cognitive control and should also be considered as a source of age-related deficits in dual-task.

In a recent set of studies, Bherer et al. (2005; 2006; 2008) examined the extent to which dual-task performance with two discrimination tasks, as typically used in PRP studies, can be enhanced in older adults. The authors explored the potential improvement when two concurrent tasks require similar manual responses but different input modalities (Bherer et al., 2005) and when the two tasks shared the same input and output modality (Bherer et al., 2008). In these studies, two discrimination tasks were treated as equally important instead of treating the tasks in a sequential order as in a typical PRP paradigm. Treating the tasks as equally important is thought to favor parallel processing of the two tasks. Participants were also provided with real-time individualized feedback (independently for each task) in the form of a graph presented on the computer screen; as such feedback appeared important in previous dual-task training studies (Kramer et al., 1995; 1999). Bherer et al. (2008) observed that even with similar motor responses and two visual stimuli, both older and younger adults showed substantial gain in performance after training.

Thus far, laboratory based cognitive training studies have shown positive results in improving attentional control in older adults, with both complex and simple dual-task combinations, which suggest that cognitive plasticity in attentional control is still possible in old age. However, the extent to which transfer could be expected to non-trained tasks remained to be documented. The transfer effects are important to show that attentional control improved through training and that learning entailed more than specific stimulus-response mappings (Batsakes & Fisk, 2000; Ho & Scialfa, 2002). Many previous studies have found narrow transfer after cognitive training (e.g., Ball et al., 2002). However, other studies in the literature suggest transfer of training, at least in dual-task paradigms, between quite different sets of stimuli and tasks (Kramer et al., 1995, 1999). In the studies conducted by Bherer et al. (2005, 2008), transfer effects were observed after dual-task training in new task combinations involving the same input and output conditions (within-modality transfer task) or a different combination of input and output conditions (cross-modality transfer task). This is an important finding and suggests that dual-task skills were improved through training, and that learning entailed more than specific stimulus-response mappings (Batsakes & Fisk, 2000; Ho & Scialfa, 2002). The transfer data suggest that subjects learned a set of skills that entail the ability to coordinate the performance of multiple tasks. Despite such positive and encouraging results, Bherer et al. (2008) concluded that whether such skills will generalize beyond two-choice discrimination tasks is an important question for future research, since few studies have shown evidence of transfer effect after cognitive training and those that have done so used transfer tasks that shared close similarities with the training task.

Studies looking at transfer effect in situations that differ greatly from training have shown limited results. Ball et al. (2002) have verified if the effect of a speed processing training, under a divided attention format, would generalize to tasks related to daily functioning. The results failed to show improvements in the test of daily functioning. However, using a training program analogue to Ball et al. (2002), Edwards et al. (2002, 2005) and Roenker, Cissell, Ball, Wadley, and Edwards (2003) obtained transfer effects with everyday speed measures; the Timed Instrumental Activities of Daily Living (Timed IADL), the Road Sign Test (RST) and reported transfer to on-the-road driving performance. However, Edwards et al. (2002, 2005) also tested the extent to which cognitive training lead to transfer effect in other cognitive domains using wider range of clinical tests (e.g., classical Stroop Test, Trail Making Test, Digit-Symbol Substitution, Digit and Spatial Span) and found no evidence of transfer.

The absence of transfer effect in neuropsychological tests after speed of processing training in Edwards et al's study could be explained by the fact that they are more sensitive to changes in attention and attentional control functions, rather than merely speed of processing. In fact, according to Brenes (2003), cognitive training can lead to transfer effects in new tasks that require the cognitive functions that have been trained. In other words, to obtain transfer effect of training to untrained situation, the training and the transfer condition should tap the same attentional mechanisms. Following this argument, it is reasonable to believe that dual-task cognitive training would lead to improvement in mechanisms that support divided attention (reduced interference between concurrent tasks and enhanced ability to switch between tasks). The results reported by Bherer et al. (2005) support this view since the authors observed that dual-task training enhanced attentional control in two different ways. First, dual-task training enhanced the capacity to maintain stimuli and response alternatives in working memory, hence diminishing interference. Second, cognitive training also improved task coordination skills. Bherer et al. did not explored whether these enhanced attentional control behaviors would be observable in clinical tests that assess attentional control. However, one could expect improvement in neuropsychological tests used in clinic for their capacity to highlight attentional control deficits.

The aim of the present study was to explore whether dual-task training would lead to significant improvement in clinical tests often used with older adult's population to assess attentional control. A group of older adults performed a dual-task training program along with a neuropsychological tests battery of attention tests prior to and after the training regiment. Following Brenes (2003) hypothesis, we expected that although improvement could be observed in processing speed and attention in general, larger improvement should be observed in tests conditions that put heavy demands on attentional mechanisms that support multiple task performances.

Method

Participants

Thirty-four community dwelling individuals participated in the study. Participants were 27 women and 7 men with a mean age of 72 years (*SD* = 6) and an average of 13 years of school education (*SD* = 3.8). All participants reported good health (on a 5-point scale, the mean score was 4.3) and none of them had surgery with general anesthesia within six months prior testing. They had no history of neurological or psychiatric diseases and none of them were taking medications known to have an influence on cognition.

In a 45 minutes pre-screening session, all participants completed a perceptual screening questionnaire which served to detect the presence of visual or auditory impairments. Moreover, The Mini Mental State Examination (Folstein, Folstein, & McHugh, 1975; cut-off score for inclusion in the study was 26/30) was used to exclude older participants suffering from dementia. Mean score was 29/30, with a range of 27-30.[2] Participants' general cognitive abilities were also assessed with a psychometric tests battery that included Digit Span (WAIS-III), Similarities (WAIS-III) and Verbal Fluency Test (number of words starting with P-T-L generated in 90 s). Participants' characteristics are shown in Table 1.

[2] A main effect of Group was observed at the MMSE between control (mean = 29.47) and training (mean = 28.88) groups, $F(1, 32) = 5.88$, $p < .05$, $\eta^2 = .16$. When we removed the lowest score (27) obtained by a participant, we obtained a mean score of 29 for the Group and the main effect in favor of control group was yet again observed, $F(1, 31) = 4.63$, $p < .05$, $\eta^2 = .13$. However this difference is not clinically relevant.

Apparatus

A computerized dual-task training program was specifically designed for the purpose of this study (see Figure 1). Participants were seated in front of a computer (Pentium4) in a quiet room and hands were put on the keyboard. Following instructions, participant initiated the task himself by pressing the space bar on the keyboard. Trial started with a fixation point presented in the middle of the screen and lasting 2000ms. Then, a stimulus from one of the two tasks or stimuli from the two tasks simultaneously were presented. Stimulus remained on the screen for 3000ms or until participant provided a response.

The dual-task program involved two visual tasks: form discrimination and symbol categorization. The forms discrimination task required indicating whether a circle or a square appeared on the screen by pushing one of two keys associated to each stimulus. In the symbol categorization task, participants indicated whether a letter (drawn from A to I) or a number (drawn from 1 to 9) appeared on the screen. Participants provided their answer on the computer keyboard, one hand devoted to one task. The hand-task mapping was maintained constant for each participant for the entire duration of the study, but counterbalanced across participants. Participants provided their answer with the index and the middle finger of each hand (corresponding to keys « A », « S », « K » and « L » on the keyboard). Stimulus-response mapping remained on the screen throughout the experiment to avoid any confound related to forgetting hand-task assignment. Moreover, a tone indicated an incorrect response.

Procedure

Neuropsychological tests and questionnaires. After the pre-screening session (described above), participants were randomly assigned to either the training or the control group. All participants completed the same pre-test and post-test sessions, but only the training group completed the 6 training sessions. Pre-testing took place in a 90-minute session during which the Geriatric Depression Scale (Yesavage et al., 1983) was completed (cut-off score of 11). The Divided Attention Questionnaire (Tun & Wingfield, 1995) and the Cognitive Failures Questionnaire (Broadbent, Cooper, FitzGerald, & Parkes, 1982) permitted the participants to self-evaluate themselves in a daily life situations requiring attentional control. During the pre-test session, participants also completed a neuropsychological tests battery to assess processing speed, attention and attention control (Lezak, 2004). The tests battery included the following standardized neuropsychological transfer tasks:

1. Digit Symbol-Coding (WAIS-III): In this visuomotor and coordination speed test the participant copies a symbol corresponding to a number, using a key associating each number with a specific symbol. The participant's score corresponds to the number of symbols correctly drawn within 120 seconds (maximum score = 133 points).

2. Stroop Color-Word Test: We used the modified Stroop test by Bohnen, Jolles, & Twijnstra (1992) and adapted in French by Chatelois et al. (1996). The test involves four different conditions, each including 100 stimuli (10 items per line) printed on a 21.5 x 28 cm sheet of paper. In the word reading condition, participants

must read as fast as possible words that represent four colors printed in black ink. In the color naming condition, participants must name the colors of rectangles printed in red, green, blue and yellow. In the color-word interference condition, color-words are printed in a color that differed from their meaning (e.g., the word blue printed in green) and participants must name the color of the printing while ignoring the meaning of word. In the color-word flexibility condition, participant performs a color-word interference condition, except that printed rectangles were randomly placed around 20 color-words out of the 100 items. A rectangle indicated to the participant that he must read the word instead of naming its color. This fourth condition adds a switching component to the classical Stroop task by asking participant to alternate from naming the color of the word to reading the word. Participants had to complete the four conditions as fast as possible. Variable of interest is the time to complete each of the four conditions and number of errors corrected spontaneously by the participants (corrected errors).

3. Trail Making Test: This test assesses psychomotor coordination speed, visual scanning ability and attentional flexibility. In part A, the participant had to draw a line between numbers in ascending order as fast as possible. In part B, 25 circles containing each 12 letters (A to L) and 13 numbers (1 to 13) are randomly arranged on a sheet of paper. The participant had to trace a line alternating between numbers and letters in a sequential order. The experimenter noted the time required to complete part A and B. Comparing performance in part B and A allows to isolate the contribution of attentional flexibility.

4. Symbol Search (WAIS-III): In this processing speed and attention test, participants find two target symbols printed in the left portion of a sheet among 5 symbols presented on the same line in the right portion of the printed sheet. The participant indicated if one of the two targets was present or absent by marking the words "yes" or "no" printed on the answer sheet. The test comprised 15 different lines on four sheets. Performance score corresponds to the number of correct answers completed in 2 minutes (maximum score = 60 points).

5. Letter-Number Sequencing (WAIS-III): In this test, series of letters and numbers are presented in mixed order to the participants. The participant had to recall orally the numbers in ascending order first and then the letters in alphabetic order (Maximum score = 21 points). This test assesses the ability to manipulate information in working memory.

Baseline dual-task performance. In addition to the neuropsychological tests battery, the pre-test session also involved a short version of the dual-task paradigm used during the training in other to establish a baseline level of performance in the training task in both the training and the control groups. In this dual-task paradigm participants completed three types of trial. First, participants completed each task alone at the beginning and at the end of the pre-test session. These trials are referred to as single-pure trials and serve to indicate performance baseline and improvement in the ability to complete one of the two tasks. After two blocks of single-pure trials, one for each task, participants completed the dual-task condition in which stimulus from one task or from the 2 tasks simultaneously could be presented. Thus, two types of trials could occur during the dual-task block, a single-mixed trial (only one of the two tasks) and a dual-mixed trial (two tasks in concurrent completion). These three types of trial (single-pure, single-mixed and dual-mixed) were used by Bherer et al. (2005, 2008) and allowed assessing task-set cost and dual-task cost. The task-set cost (RT in single-mixed trials – RT in single-pure trials) indicated the cost of performing a given task in the context of a dual-task situation. The dual-task cost (RT in dual-mixed trials – RT in single-mixed trials) indicates the cost of coordinating two tasks that must be completed concurrently. The pre-test session included 2 blocks of 40 single-pure trials (one of each task), for a total of 80 single-pure trials, followed by 4 blocks of 40 mixed trials (20 single-mixed and 20 dual-mixed trials), and followed again by two additional single-pure blocks of 40 trials each.

The dual-task training program. Following the pre-test, older adults from the training group undertook six sessions of dual-task cognitive training lasting about 45 minutes. Participants completed one session by day and must have completed the sixth session within a three-week delay. The six training sessions were similar to the one in pre-test/post-test sessions and took the form of 2 blocks of single-pure trials followed by mixed blocks composed of single-mixed and dual-mixed trials, and followed again by 2 blocks of single-pure trials. A major difference from the pre-test was that the participants completed 8 mixed-blocks instead of 4 as in the pre-test session. After each training session, participants have completed 160 single-pure, 160 single-mixed and 160 dual-mixed trials.

Training sessions also differed from pre-test/post-test sessions by providing individualized performance feedback to the participant (see Bherer et al., 2005 and Kramer, Larish, & Strayer, 1995, on the importance of feedback on training studies). The feedback took the form of an odometer presented on the left upside part on the computer screen (see Figure 1). The needle of the odometer moved according to respond speed and the color of the left portion of the odometer indicated to the participant whether the performance was appropriate. In pure blocks, the left portion of the odometer appeared in red, green or yellow when the mean RT of the last 5 trials was respectively; higher than the mean RT for the entire block multiplied by a ratio of 1.8, equal or smaller than the mean of the block divided by a ratio of 1.8 or in between these two criteria. In the mixed blocks, the feedback depends on the ratio of the dual-mixed trials on the single-mixed trials. The left portion of the odometer appeared in red (slow performance) when the mean RT for the last 5 dual-mixed trials was larger or equal to the mean RT of the simple-mixed trials multiplied by a ratio of 3.6. It appeared in green (good performance) when the mean RT for the last 5 dual-mixed trials was smaller or equal to the mean RT of the simple-mixed trials multiplied by a ratio of 1.6. The left portion of the odometer appeared yellow when performance was between these two criteria. This calculation procedure, not explained to the participants, was intended to help participants to achieve a level of performance in dual-task trials close to the one obtained in single-task trials.

Post-test and retention session. Participants of both training and control groups completed a post-test session after the 4-week delay and a retention session, one month later. Post-test and retention sessions were identical to the pre-test.

Results

Two sets of analyses were performed separately. The first set of analyses explored participants' performance during the six training sessions in order to assess training effect. Based on previous studies with a similar dual-task training protocol (Bherer et al., 2005), we expected significant training gain in both response speed and accuracy. A second set of analyses was performed to compare pre-test vs. post-test performance and post-test vs. retention session performance in dual-task performance, as well as in the neuropsychological tests. In these analyses, comparing training and control participants allowed us to assess training effect in comparison with a mere test-retest effect.

Training Sessions

The dependent variables of interest in the training tasks were response time (RT) and accuracy (%). RT was calculated from stimulus presentation to the subject's response. Incorrect responses were not included in the RT analyses, and trials were also rejected if the RT was longer than 3000ms or shorter than 100ms. Accuracy was calculated as the percentage of correct responses in each condition. Analyses were performed using ANOVAs with three within-subject factors, Task (symbols categorization and forms discrimination), Sessions (1 to 6), and Trial Types (single-pure, single-mixed, dual-mixed). Significant interactions between these factors were decomposed with simple-effects. However, in the case of a significant interaction with more than two levels of a repeated-factor (e.g., 6 training sessions, 3 trial types), repeated-contrasts were used. Such analyses provide a comparison of RT differences between two consecutive levels of a repeated factor. Statistical analyses of the data were performed with SPSS (SPSS Inc.), which provides adjusted alpha levels (Greenhouse-Geisser) for within-subject factors to correct for violations of homogeneity of variance. Alpha level for significant effect was set at .05 and adjusted alpha levels were used when required, that is when the Mauchly's test of sphericity was significant (SPSS, 2003). Effect sizes (η^2) are also reported. Preliminary analyses with RT indicated no interaction between Task and Training effect. For this reason, data were collapsed between the two visual tasks[3].

Reaction Time Analyses

Figure 2a shows RTs as function of the six training sessions. Several important results were observed. A main effect of Trial Types was obtained, $F(2, 32) = 409.25, p < .001, \eta^2 = .96$. Follow-up analyses indicated that the effect concerns

[3] Note that in both set of analyses (Training sessions as well as Pre vs. Post-test sessions) with RT, a significant Task effect was observed (Training; $F(1, 16) = 5.27, p < .05, \eta^2 = .25$, Pre-Post test; $F(1, 31) = 41.88, p < .001, \eta^2 = .58$), which indicated faster RT in the form discrimination task compared to the symbol categorization task. This is not surprising as the symbol categorization task is more difficult because participants indicated whether a letter (A to I) or a number (1 to 9) appeared on the screen while the form discrimination task require to discriminate between two shapes only, a circle or a square. We also observed a Task by Trial Types interaction (Training; $F(2, 32) = 5.42, p < .05, \eta^2 = .25$, due to larger dual-task cost in the forms discrimination task (550ms) compared to the dual-task cost observed in the symbols categorization task (387ms), $F(1, 16) = 6.08, p < .05, \eta^2 = .28$. In the ANOVA performed on Pre-test vs. Post-test data, a Task x Group x Trial Types, $F(2, 62) = 4.99, p < .05, \eta^2 = .14$, was also obtained. Follow up analyses (training and control separately) indicated a larger dual-task cost in the forms discrimination task (577 ms) compared to the symbols categorization task (374ms) in the training group only, $F(1, 16) = 7.27, p < .05, \eta^2 = .31$. Importantly, these effects did not change over session, which suggests that training effect was equivalent in both tasks.

both, task-set cost and dual-task cost. In fact, repeated-contrasts showed that RT was longer in single-mixed trials (761ms), compared to those performed in the single-pure trials (591ms), $F(1, 16) = 377.93$, $p < .001$, $\eta^2 = .96$. This indicates a significant task-set cost in RT (170ms). It was also observed that RT was slower in dual-mixed trials (1229ms) compared to single-mixed trials (761ms), $F(1, 16) = 350.21$, $p < .001$, $\eta^2 = .96$. Thus, significant dual-task cost was also observed (468ms).

With regard to the effect of training, a main effect of Session, $F(5, 80) = 14.58$, $p < .001$, $\eta^2 = .48$, was observed. Repeated-contrasts indicated that RT got faster from Session 1 to Session 2, $F(1, 16) = 5.65$, $p < .05$, $\eta^2 = .26$, from Session 2 to Session 3, $F(1, 16) = 11.49$, $p < .01$, $\eta^2 = .42$, and from Session 3 to Session 4, $F(1, 16) = 7.25$, $p < .05$, $\eta^2 = .31$. Subsequently, RTs didn't show significant improvement. However, a significant Session X Trial Types interaction, $F(10, 160) = 6.57$, $p < .001$, $\eta^2 = .29$, indicated that training had a differential impact on the trial types. Repeated-contrasts showed that this interaction was due to decrease in task-set cost between session 1 and 2, $F(1, 16) = 10.34$, $p < .01$, $\eta^2 = .39$, and between session 2 and 3, $F(1, 16) = 10.38$, $p < .01$, $\eta^2 = .39$. Decrease in task-set cost was not significant between session 5 and 6, $F(1, 16) = 3.83$, *ns*. Modest improvement was also observed in dual-task cost, between session 3 and 4, but it did not reach significance, $F(1, 16) = 3.41$, *ns*, and no further improvement was observed in dual-task cost.

Accuracy Analyses

Data were analyzed with the same ANOVA model as used in the RT analyses, with Task, Sessions, and Trial Types as within-subject factors. Percentages of correct responses, over the six training sessions, are presented in Figure 2b. First, a main effect of Trial Types, $F(2, 32) = 108.57$, $p < .001$, $\eta^2 = .87$, was observed due to a significant task-set cost, $F(1, 16) = 180.53$, $p < .001$, $\eta^2 = .92$. Accuracy was higher in single-pure trials (98.17%) compared to single-mixed trials (94.94%). However, accuracy was equivalent in dual-mixed trials (94.47%) and single-mixed trials (94.94%), indicating no substantial dual-task cost, $F(1, 16) = 3.39$, *ns*.

With regard to training effect, the main effect of Session was significant, $F(5, 80) = 16.14$, $p < .001$, $\eta^2 = .50$. Similar to RT analyses, repeated-contrasts showed significant improvements in accuracy between Session 1 and 2, $F(1, 16) = 5.09$, $p < .05$, $\eta^2 = .24$, and between Session 3 and 4, $F(1, 16) = 19.88$, $p < .001$, $\eta^2 = .55$. No other effect or interaction effect reached significant level in accuracy data.

Pre-test Versus Post-test Analyses

This section reports the results observed from pre-test to post-test in the training group compared to the performance of the control group[4], which did not engage in dual-task training. Data from the experimental dual-task training are presented first (RT and accuracy analyses), followed by the results obtained in the neuropsychological tasks.

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[4] Data were excluded for one participant from the control group who did not follow the instruction of the dual-task procedure.

Dual-Task

RTs and accuracy data were analyzed with ANOVAs involving one between subject factor, Group (Training vs. Control), and three within-subject factors, Task (symbols categorization and forms discrimination), Sessions (pre-test vs. post-test), and Trial Types (single-pure, single-mixed, dual-mixed). Here again, significant interactions with more than two levels of a repeated-factor (e.g., 3 trial types) were decomposed with repeated-contrasts between two consecutive levels of a repeated factor. Adjusted alpha levels (Greenhouse-Geisser) are used to correct for violations of homogeneity of variance.

Reaction time analyses. Average RTs in the pre-test and post-test sessions are shown in Figure 3a. The main effect of Trial Types was significant, $F(2, 62) = 571.68$, $p < .001$, $\eta^2 = .95$. Reaction time was longer in the single-mixed trials compared to single-pure trials (significant task-set cost = 246ms), $F(1, 31) = 234.90$, $p < .001$, $\eta^2 = .88$. Moreover, RT was longer in the dual-mixed trials compared to the single-mixed trials (significant dual-task cost = 456ms), $F(1, 31) = 595.62$, $p < .001$, $\eta^2 = .95$.

With regard to training effect on dual-task performance, the main effect of Session was significant, $F(1, 31) = 67.56$, $p < .001$, $\eta^2 = .69$, as was the interaction with the Group X Session, $F(1, 31) = 31.58$, $p < .001$, $\eta^2 = .51$. Simple effects indicated a significant improvement in RT from pre-test to post-test in the training group (1083ms to 832ms), $F(1, 31) = 98.75$, $p < .001$, but not in the control group (1092ms to 1045ms), $F(1, 31) = 3.28$, *ns*.

The results also indicated a significant Session X Trial Types interaction, $F(2, 62) = 13.00$, $p < .001$, $\eta^2 = .30$, along with an interaction between Group X Session X Trial Types, $F(2, 62) = 3.56$, $p < .05$, $\eta^2 = .10$, which suggests that the training program had a differential impact on dual-task cost and task-set cost. This was confirmed by the results from ANOVAs performed separately for each group. In the training group, results showed a significant effect of Session, $F(1, 16) = 82.42$, $p < .001$, $\eta^2 = .84$, and a significant interaction between Session and Trial Types, $F(2, 32) = 10.87$, $p < .001$, $\eta^2 = .41$, due to a significant decrease in task-set cost (311ms-126ms = 185ms), $F(1, 16) = 20.61$, $p < .001$, $\eta^2 = .56$, with no significant improvement in dual-task cost (493ms – 458ms = 35ms), $F(1, 16) < 1$, *ns*. In the control group, the Session effect, $F(1, 15) = 4.16$, *ns*, and the Session X Trial Types interaction, $F(2, 30) = 2.67$, *ns*, did not reach significance.

Accuracy analyses. Percentages of correct responses were analyzed with a similar statistical model as the one used with RT. Mean accuracy data obtained in pre-test and post-test sessions are shown in Figure 3b. First, a main effect of Trial Types was observed, $F(2, 62) = 72.13$, $p < .001$, $\eta^2 = .70$, due to a significant task-set cost, $F(1, 31) = 62.98$, $p < .001$, $\eta^2 = .67$, and a significant dual-task cost, $F(1, 31) = 21.78$, $p < .001$, $\eta^2 = .41$.

With regard to training effect, we observed a significant effect of Session, $F(1, 31) = 26.23$, $p < .001$, $\eta^2 = .46$, along with a significant Session X Group, $F(1, 31) = 12.71$, $p < .001$, $\eta^2 = .29$, and a Session X Trial Types interaction, $F(2,62) = 9.62$, $p < .001$, $\eta^2 = .24$. These two interaction were qualified by a Group X Session X Trial Types interaction, $F(2, 62) = 5.41$, $p < .01$, $\eta^2 = .15$. When separate ANOVAS were performed for each group, the training group showed a significant Session effect (91.65 to 97.40%), $F(1, 16) = 22.53$, $p < .001$, $\eta^2 = .59$, and a significant Session X Trial Types interaction, $F(2, 32) = 10.00$, $p < .001$, $\eta^2 = .39$, with a significant decrease in task-set cost (single-mixed - single-pure), $F(1, 16) = 6.50$, $p < .05$, $\eta^2 = .29$, and in dual-task cost (dual-mixed - single-mixed), $F(1, 16) = 6.18$, $p < .05$, $\eta^2 = .28$, between pre-test and post-test session. In the control group, a effect of Session (94.98 to 96.01%) was observed, $F(1, 15) = 5.22$, $p < .05$, $\eta^2 = .26$, but the Session X Trial Types interaction was not significant, $F(2, 30) < 1$, *ns*.

Neuropsychological Tests and Questionnaires

One major goal of the present study was to investigate whether training effects generalized to clinical tasks that assessed attention, with a particular emphasize on tests that involve attentional control functions that support performance of concurrent multiple tasks, such as divided attention and switching. Age-related differences have been well documented in these clinical tests (see Lezak, Howieson, & Loring, 2004) and this has been interpreted has evidence of age-related impairment in executive and attentional control functions. The ANOVA model used here included Group (training and control) as between-subject factor and Session (pre-test/post-test or post-test/retention session) as within-subject factor. Significant interactions between these factors were decomposed with simple-effects. The results of the two groups of participants (training and control) are presented in Table 2. Only significant interactions between Group and Session are reported in details here.

In the Symbol Search Test, a significant Session effect was observed, $F(1, 32) = 6.22$, $p < .05$, $\eta^2 = .16$, but the interaction between Group and Session was not significant, $F(1, 32) < 1$, *ns*. In the Letter-Number Sequencing, the Geriatric Depression Scale, the Divided Attention Questionnaire and the Cognitive Failures Questionnaire, there was no significant session effect or interaction between Group and Session.

Positive effects of training (Group X Session interaction) were observed in several tests, including Digit Symbol-Coding Test, the Trail Making Test and the Stroop Color-Word Test[5]. Clinical neuropsychological test sometimes show large interindividual differences in older adults that could produce confounding effects (Lezak, Howieson, & Loring, 2004). For this reason, results were analyzed with raw data, along with percentage scores of improvement that take into account baseline level of performance. Furthermore, we were concerned that our two groups of participants differed significantly on MMSE score at baseline and thus, when a

[5] Note that a participant from the training older group did not complete the Stroop Color Word Test due to color-blinding.

significant interaction that involved the Group factor was obtained; ANCOVAs were performed using MMSE score as covariable. Except specified otherwise, the Group X Session interaction remained significant in the ANCOVA.

A main effect of Session, $F(1, 32) = 10.76$, $p < .01$, $\eta^2 = .25$, and a Group X Session interaction were observed in the Digit Symbol-Coding Test, $F(1, 32) = 5.00$, $p < .05$, $\eta^2 = .14$, (ANCOVA with MMSE, $F(1, 31) = 3.63$, $p = .066$, $\eta^2 = .11$), due to significant improvement between pre-test and post-test in the training group, $F(1, 32) = 15.21$, $p < .001$, but not in the control group, $F(1, 32) < 1$, *ns*. Univariate ANOVA performed on the percentage of change after training (post-test − pre-test/ pre-test*100; see Figure 4) also revealed that improvement was larger in the training group compared to the control group, $F(1, 32) = 4.71$, $p < .05$, $\eta^2 = .13$ (ANCOVA with MMSE, $F(1, 31) = 3.92$, $p = .057$, $\eta^2 = .11$).

In the Trail Making Test Part A, a significant Session effect was observed, $F(1, 32) = 10.26$, $p < .01$, $\eta^2 = .24$, but the interaction between Group and Session did not reach significant level, $F(1, 32) = 4.02$, *ns*. The same was observed in the Trail Making Test Part B[6], which showed a significant Session effect, $F(1, 31) = 7.39$, $p < .01$, $\eta^2 = .19$, with no significant interaction between Group and Session, $F(1, 31) = 2.67$, *ns*. However, in the Trail Making Test, a score can be calculated to isolate the attentional cost associated to the switching component from the part B

[6] Note that the data from one participant was excluded in the Trail Making Test Part B due to abnormal performance. The participant performed normally at all other tests and in the Trail Making Test Part A as well.

after controlling for baseline performance ((Trail B – Trail A)/ Trail A). This switch cost indicates ones ability to switch attention between tasks (alternate search between letters and numbers), which is highly relevant in dual-task situations. An analysis performed on the switch cost (see Figure 5) showed a significant Group X Session interaction, $F(1, 31) = 7.60$, $p < .01$, $\eta^2 = .20$ (ANCOVA with MMSE, $F(1, 30) = 8.31$, $p < .01$, $\eta^2 = .22$), due to significant improvement in the training group from pre-test to post-test, $F(1, 31) = 6.19$, $p < .05$, which was not observed in the control group, $F(1, 31) = 1.94$, *ns*.

In the Stroop Color-Word test (see Table 2 for results), there was no significant session effect or interaction between Group and Session in the word reading condition. In the interference condition, the Session effect was significant, $F(1, 31) = 26.79$, $p < .001$, $\eta^2 = .46$, but there was no interaction between Group and Session, $F(1, 31) < 1$, *ns*. However, a Group X Session interaction was observed in the colors naming condition, $F(1, 31) = 6.58$, $p < .05$, $\eta^2 = .18$ (ANCOVA with MMSE, $F(1, 30) = 4.72$, $p < .05$, $\eta^2 = .14$). The training group completed the test more quickly at post-test compared to pre-test, $F(1, 31) = 9.28$, $p < .01$, while performance in the control group did not improve, $F(1, 31) < 1$, *ns*. Percentage of change in this condition was also larger in the training compared to the control group, $F(1, 31) = 6.84$, $p < .01$, $\eta^2 = .18$. Note also that a Group X Session interaction was obtained for corrected errors in this test, $F(1, 31) = 5.68$, $p < .05$, $\eta^2 = .16$, (ANCOVA with MMSE, $F(1, 30) = 1.82$, *ns*), due to a significant reduction in corrected errors after training in the training group, $F(1, 31) = 8.24$, $p < .01$, while performance did not change in the control group, $F(1, 31) < 1$, *ns*.

A much more relevant condition of the modified Stroop task in the context of dual-task training is the flexibility condition in which participants must alternate between naming the color and reading the color-words (Bohnen, Jolles, & Twijnstra, 1992). In this condition, a main effect of session, $F(1, 31) = 40.08$, $p < .001$, $\eta^2 = .56$, and a Group X Session interaction, $F(1, 31) = 12.25$, $p < .001$, $\eta^2 = .28$, was observed in the time to complete the test (ANCOVA with MMSE, $F(1, 30) = 12.12$, $p < .01$, $\eta^2 = .29$). This was due to a larger improvement in the training group, $F(1, 31) = 46.91$, $p < .001$, compared to control group, $F(1, 31) = 4.13$, $p = .051$. As can be seen in Figure 6, percentage of change also showed larger improvement in the training group compared to control participants, $F(1, 31) = 9.5$, $p < .01$, $\eta^2 = .24$. A significant Group X Session interaction was also observed for corrected errors, $F(1, 31) = 13.23$, $p < .001$, $\eta^2 = .30$, (ANCOVA with MMSE, $F(1, 30) = 9.92$, $p < .01$, $\eta^2 = .25$). Follow-up analyses indicated that the training group made less errors after training, $F(1, 31) = 13.97$, $p < .001$, while errors produced by the control group did not change from pre-test to post-test, $F(1, 31) = 1.88$, *ns*. The benefit of training on corrected errors in the flexibility condition of the Stroop test was also confirmed by a larger percentage of improvement in the training group, $F(1, 31) = 5.68$, $p < .05$, $\eta^2 = .16$ (see Figure 7).

Post-test Versus Retention Session Analyses

This section reports the results observed from post-test to the retention session completed one month after the training in both control and training groups. RTs and accuracy data were analyzed with ANOVAs involving Group (Training vs. Control) as between subject factor, and three within-subject factors, Task (symbols categorization and forms discrimination), Sessions (post-test vs retention session), and Trial Types (single-pure, single-mixed, dual-mixed). Again, repeated-contrasts were used in the case of significant interactions with more than two levels of a repeated-factor (e.g., 3 trial types) and adjusted alpha levels (Greenhouse-Geisser) are used to correct for violations of homogeneity of variance.

Dual-Task

Reaction time analyses. The main effect of Trial Types was significant, $F(2, 58) = 401.28$, $p < .001$, $\eta^2 = .93$, due to a significant task-set cost (203ms), $F(1, 29) = 243.70$, $p < .001$, $\eta^2 = .89$, and a significant dual-task cost (451ms), $F(1, 29) = 329.50$, $p < .001$, $\eta^2 = .92$. The main effect of Session between post-test and retention session was also significant, $F(1, 29) = 5.74$, $p < .05$, $\eta^2 = .17$, as was the interaction between Group X Session, $F(1, 29) = 22.32$, $p < .001$, $\eta^2 = .44$. Simple effects indicated a slight but significant increase in RT between post-test and retention session in the training group (832ms to 914ms), $F(1, 29) = 28.07$, $p < .001$, while RT did not change over time in the control group (1052ms to 1025ms, $F(1, 29) = 2.47$, *ns*).

The results also indicated a Session X Trial Types interaction, $F(2, 58) = 3.56$, $p < .05$, $\eta^2 = .11$, due to a larger task-set cost in the retention session (218ms) compared to the post-test session (187ms), $F(1, 29) = 4.77$, $p < .05$, $\eta^2 = .14$. Importantly, this effect did not vary among Group (Session X Trial Types X Group, $F(2, 58) = 2.26$, *ns*).

Accuracy analyses. Accuracy data indicated a main effect of Trial Types, $F(2, 58) = 28.89$, $p < .001$, $\eta^2 = .50$, with a significant task-set cost, $F(1, 29) = 91.21$, $p < .001$, $\eta^2 = .76$, and a significant dual-task cost, $F(1, 29) = 4.71$, $p < .05$, $\eta^2 = .14$. With regard to training effect, accuracy did not change significantly between post-test and retention session, $F(1, 29) = 1.33$, *ns*, and did not vary as a function of Group (Session X Group, $F(1, 29) = 3.32$, *ns*).

Neuropsychological Tests and Questionnaires

Results from the neuropsychological tests and questionnaires performed in the retention session are presented in Table 2. We did not observe any group difference (Group effect or interaction involving group) in the retention analyses. This indicates that the improvements observed at post-test in the neuropsychological tests last over the one-month retention period.

Discussion

The aim of this study was to assess whether computerized dual-task training could lead to significant improvement in clinical neuropsychological tests in older adults. Based on previous studies that have shown significant improvement in older and younger adults in dual-task performance, a dual-task training program was designed for older adults. As reported in previous studies, participant engaged in the training program showed significant improvement in dual-task performance, which was not observed in control participants. These results bring further support to the notion that cognitive plasticity for attentional control functions as required for performing concurrent task remains possible as one grows older.

An original contribution of the present study was to explore the benefit observed after dual-task training in clinical neuropsychological tests frequently used with older adults' population to characterize attention and attentional control deficits. The clinical test battery involved tests of processing speed, attention, and attentional control mechanisms such as switching and inhibition (Digit Symbol, Stroop Color-Word Test, Trail Making Test, Symbol Search and Letter-Number Sequencing). It was expected that the larger training effect would be observed in tests that tap attentional control mechanisms that are involved when one performs concurrent tasks, such as switching attention between tasks (assessed with the flexibility condition of the modified Stroop Color-Word Test and the Trail Making Test Part B). These tests are thought to rely on cognitive mechanisms involved in dual-task situation and are typically used with older adults to assess attentional control functions. Moreover, since the feedback procedure used in the training program encouraged participants to strive for speeded responses, it was anticipated that processing speed would also improve.

Results from the present study showed significant improvement in dual-task performance after training. In fact, response speed and accuracy significantly improved in the training group, but not in the control group. In the training group, improvement in speed and accuracy in dual-task condition suggests that the training procedure was effective in improving task coordination skills. These results are consistent with previous studies using an analogue procedure (Bherer et al., 2005; Kramer, Larish, Weber, & Bardell, 1999). More important to our concern, results also indicated significant transfer effects to clinical tests. In fact, the training group also showed improvement in the flexibility condition of the Stroop Color-Word test, both in speed and accuracy, which was not observed in the control group. Significant reduction was also observed in the switching cost of the Trail Making Test (using the following equation; Part B − Part A/Part A). Finally, dual-task training did also lead to better performance in processing speed as measured with the Digit Symbol-Coding test and the color naming condition of the Stroop Color-Word Test.

Before discussing the implication of the results regarding the transfer to the clinical tests, it seems important to outline the characteristics of the dual-task training procedure that was used in the present study. First, the training involved individualized-adaptive feedback throughout the training sessions. This seems to be a major component of training since previous studies that have shown equivalent and significant improvement in older and younger adults after attention training (Bherer et al., 2008), and sometimes a larger gain in older adults (Kramer et al., 1995; 1999), used continuous adaptive feedback. It is likely that feedback allows participants to better adjust their performance to the task requirements and help them to strive for fast and accurate responses. Another potential explanation is that individual feedback during cognitive training favors participant's self-evaluation and development of more effective attentional control strategies. Another interesting aspect of the dual-task training used in this study was to dissociate improvement in task-set cost (RT in single-mixed trials – RT in single-pure trials) and dual-task cost (RT in dual-mixed trials – RT in single-mixed trials). The improvement observed in task-set cost can be viewed as an improvement to prepare and maintain multiple tasks sets, and suggests that older adults are able to reduce the burden of task requirements through training. This is an important finding if we considered that previous research with the task-switching paradigm has shown that older adults have considerable difficulty when they need to be prepared to respond to multiple tasks as compared to a single task (Kray & Lindenberger, 2000; Mayr, 2001). Moreover, improvement in task coordination strategies, evidenced by decrease in dual-task cost, also seems to contribute to enhance dual-task performance after training in older adults. In the present study, training reduced task-set cost (both in RT and accuracy) and dual-task cost (accuracy responses only), which suggests that training help reducing the cognitive resources needed by the tasks (evidenced by task-set cost improvement) and by developing better coordination strategy (evidenced by dual-task cost improvement).

Previous studies have sometimes showed limited transfer effect after cognitive training (Edwards et al., 2002, 2005). According to Brenes (2003), cognitive training would lead to transfer effects if the transfer task involved the cognitive functions that have been trained. That is, the training and the transfer condition should tap the same functions or mechanisms. The present findings support this prediction since the dual-task cognitive training lead to larger improvement in the clinical tests' condition that allow to isolate the ability to switch among multiple response alternatives or instructions. In fact, larger improvement was observed in the flexibility condition of the Modified Stroop test that requires alternating between naming the color of the ink and reading color-words. Improvement was also evident in the switch cost of the Trail Making Test (Part B-Part A/PartA). It thus seems that dual-task training help reducing the interference between concurrent tasks and that it enhances the ability to switch between tasks.

The results reported here bring further insights on the potential benefit of cognitive training in older adults and suggest that computer-based training can lead to significant benefit outside the laboratory. However, there might be some limits regarding the broad of transfer one can expect after training. It is important to point out that the transfer tests used here have limited ecological value (see Chaytor & Schmitter-Edgecombe, 2003 for a review on the ecological validity of neuropsychological tests). Moreover, the results observed in the present study with the Divided Attention Questionnaire (Tun & Wingfield, 1995) and the Cognitive Failures Questionnaire (Broadbent, Cooper, FitzGerald, & Parkes, 1982) suggest that older adults didn't get the subjective impression of improving their attentional abilities in real life situations. It has been observed that speed of processing training can lead to significant gain in activities of daily living in older adults (Edwards et al., 2002, 2005; Roenker, Cissell, Ball, Wadley, & Edwards, 2003). However, whether dual-task training would have an impact on the daily life activities of older adults remains a matter of debate. Another important issue for future studies is the potential contribution of non-cognitive factors that might have an impact on daily life activities, such as emotional difficulties, motor deficiencies, health problems, motivation and environment requirement, and their potential mediating effect on cognitive training outcomes in older adults.

In sum, the results reported here suggest that the ability to perform multiple tasks concurrently can be improved in older adults after computerized dual-task training and that benefit can be observed in clinical neuropsychological tests of attentional control. These results suggest that cognitive training is an efficient way to improve attention control of older adults. This study also suggests that transfer effects after cognitive training are specific to task situations that involve the cognitive functions and mechanisms that have been targeted by the training regimen.

References

Allen, P.A, Lien, M. C., Murphy, M. D., Sanders, R. E., & McCann, R. S. (2002). Age differences in overlapping-task performance: Evidence for efficient parallel processing in older adults. *Psychology and Aging, 17*, 505–519.

Allen, P. A., Smith, A. F., Vires-Collins, H., & Sperry, S. (1998). The psychological refractory period: Evidence for age differences in attentional time-sharing. *Psychology and Aging, 13*, 218–229.

Ball, K., Berch, D. B., Helmers, K. F., Jobe J. B., Leveck, M. D., Marsiske, M., Morris, J. N., Rebok, G. W., Smith, D. M., Tennstedt, S. L., Unverzagt, F.W., & Willis, S.L. (2002). Effects of cognitive training interventions with older adults: A randomized controlled trial. *Journal of the American Medical Association, 288*, 2271-2281.

Batsakes, P. J., & Fisk, A. D. (2000). Age-related differences in dual-task visual search: Are performance gains retained? *Journal of Gerontology: Psychological Sciences, 55*, 332–342.

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2005). Training effects on dual-task performance: Are there age-related differences in plasticity of attentional control ? *Psychology and Aging, 20*, 695-709.

Bherer, L., Kramer, A.F., Peterson, M.S., Colcombe, S., Erickson, K., & Becic, E. (2006). Testing the limits of cognitive plasticity in older adults: Application to attentional control. *Acta Psychologica, 123*, 261–278.

Bherer, L., Kramer, A.F., Peterson, M.S., Colcombe, S., Erickson, K., & Becic, E. (2008). Transfer effects in task-set cost and dual-task cost after dual-task training in older and younger adults: Further evidence for cognitive plasticity in attentional control in late adulthood. *Experimental Aging Research, 34*, 188-219.

Bohnen, N., Jolles, J., & Twijnstra, A. (1992). Modification of the Stroop Color-Word Test improves differentiation between patients with mild head injury and matched controls. *The Clinical Neuropsychologist, 6*, 178-184.

Brenes, G. A. (2003). Cognitive training may improve targeted cognitive functions in older adults. *Evidence-Based Mental Health, 6*, 54.

Broadbent, D.E., Cooper, P.F., FitzGerald, P., & Parkes, K. R. (1982). The Cognitive Failures Questionnaire (CFQ) and its correlates. *British Journal of Clinical Psychology, 21*, 1-16.

Chatelois, J., Van Der Linden, M., Rouleau, N., De Courcy, R., Crépeau, F., & Malenfant, A. (1996). Stroop Flexibilité-4 couleurs (unpublished data).

Chaytor, N., & Schmitter-Edgecombe, M. (2003). The ecological validity of neuropsychological tests: A review of the literature on everyday cognitive skills. *Neuropsychology review, 13*, 181-197.

Dunlosky, J., Kubat-Silman, A.K., & Hertzog, C. (2003). Training monitoring skills improves older adults'self-paced associative learning. *Psychology & Aging, 18*, 340-345.

Edwards, J. D., Wadley, V.G., Myers, R. S., Roenker, D. L., Cissell, G. M., & Ball, K. K. (2002). Transfer of a speed of processing intervention to near and far cognitive functions. *Gerontology, 48*, 329-340.

Edwards, J.D., Wadley, V.G., Vance, D.E., Wood, K., Roenker, D. L., & Ball. K.K. (2005). The impact of speed of processing training on cognitive and everyday performance. *Aging & Mental Health, 9*, 262-271.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). Mini-Mental State: A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12*, 189-198.

Glass, J. M., Schumacher, E. H., Lauber, E. J., Zubriggen, E. L., Gmeindl, L., Kieras, D. E., & Meyer, D. E. (2000). Aging and the psychological refractory period: Task-coordination strategies in young and old adults. *Psychology and Aging, 15*, 571–595.

Hartley, A. A. (1992). Attention. In F. I. M. Craik, & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 3-49). Hillsdale, NJ: Lawrence Erlbaum Associates.

Hartley, A. A. (2001). Age differences in dual-task interference are localized to response generation processes. *Psychology and Aging*, *16*, 47-54.

Hartley, A. A., & Little, D. M. (1999). Age-related differences and similarities in dual-task interference. *Journal of Experimental Psychology: General, 128*, 416–449.

Hein, G., & Schubert, T. (2004). Aging and input processing in dual-task situations. *Psychology and Aging, 19*, 416–432.

Ho, G., & Scialfa, C. T. (2002). Age, skill transfer, and conjunction search. *Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 57B*, 277–287.

Kramer, A. F., Hahn, S., & Gopher, D. (1999). Task coordination and aging: Explorations of executive control processes in the task switching paradigm. *Acta Psychologica, 101*, 339–378.

Kramer, A. F., & Larish, J. (1996). Training for attentional control in dual-task settings. In W. Rogers, A. Fisk, & N. Walker (Eds.), *Aging and skilled performance: Advances in theory and applications.* Hillsdale, NJ: Lawrence Erlbaum.

Kramer, A.F., Larish, J. F., & Strayer, D.L. (1995). Training for attentional control in dual task settings: A comparison of young and old adults. *Journal of Experimental Psychology: Applied, 1*, 50-76.

Kramer, A. F., Larish, J. L., Weber, T. A., & Bardell, L. (1999). Training for executive control: Task coordination strategies and aging. In Gopher and Koriat (Eds.) *Attention and Performance* XVII (pp. 617-652). Cambridge, MA: MIT Press.

Kramer, A. F., & Madden, D. J. (2008). Attention. In F. I. M. Craik and T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp.189-249). New York: Psychology Press.

Kray, J., & Lindenberger, U. (2000). Adult age differences in task switching. *Psychology and Aging, 15*, 126–147.

Lezak, M. D., Howieson, D. B., & Loring, D. W. (2004). *Neuropsychological assessment (4th Edition)*. New York: Oxford University Press.

Mayr, U. (2001). Age differences in the selection of mental sets: The role of inhibition, stimulus ambiguity, and response-set overlap. *Psychology and Aging, 16*, 96–109.

McDowd, J. M., & Shaw, R. J. (2000). Attention and aging : A functional perspective. In F. I. M. Craik and T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp.221-292). Hillsdale, NJ: Lawrence Erlbaum Associates.

Roenker, D. L, Cissell, G. M., Ball, K. K., Wadley, V.G., & Edwards, J.D. (2003). Speed-of-processing and driving simulator training result in improved driving performance. *Human Factors, 45*, 218-233.

SPSS (2003). *Advanced Statistics 12.0*. Chicago, IL: SPSS Inc.

Tun, P. A., & Wingfield, A. (1995). Does dividing attention become harder with age ? Findings from the Dividing Attention Questionnaire. *Aging and Cognition, 2*, 39-66.

Verhaeghen, P., Steitz, W. D., Sliwinski, M. J., & Cerella, J. (2003). Aging and dual-task performance: A meta-analysis. *Psychology and Aging, 18*, 443–460.

Wechsler, D. (1997). Wechsler Adult Intelligence Scale-III. San Antonio: The Psychological Corporation.

Yesavage, J. A., Brink, T.L, Rose, T. L., Lum, O., Huang, V., Adey, M., & Leirer, V.

O. (1983). Development and validation of a geriatric depression screening scale: A preliminary report. *Journal of Psychiatric Research, 17*, 37-49.

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Table 1

Mean Scores for Participant Characteristics and General Cognitive Abilities (SD in parenthesis)

	Training	Control
Age	72.24 (6.07)	71.06 (6.25)
School Education	13.18 (4.46)	13.47 (3.20)
Mini Mental State Examination	28.88 (0.86)	29.47 (0.51)
Digit Span (Raw score on 30 points)	13.94 (2.63)	14.59 (2.06)
Similarities (Raw score on 33 points)	21.41 (6.38)	23.06 (4.51)
Phonetic Fluency Test (Total number of words)	44.71 (13.38)	43.47 (9.84)

Table 2

Mean Scores in Neuropsychological Tests and Questionnaires in Pre-test, Post-test and Retention Sessions (SD in parenthesis)

	Training			Control		
	Pre-test	Post-test	Retention	Pre-test	Post-test	Retention
Geriatric Depression Scale	3.24	4.29	3.35	4.06	3.82	3.73
(Raw score on 30 points)	(2.31)	(3.90)	(2.91)	(4.05)	(4.23)	(3.97)
Divided Attention Questionnaire	35.12	36.47	34.71	38.71	35.71	39.47
(Raw score on 75 points)	(13.06)	(12.02)	(14.36)	(8.98)	(8.04)	(11.08)
Cognitive Failure Questionnaire	36.18	34.65	34.47	38.18	36.82	39.93
(Raw score on 100 points)	(12.93)	(13.09)	(12.48)	(8.68)	(10.88)	(11.24)
Digit Symbol-Coding *	55.00	60.59	62.00	59.47	60.53	62.00
(Raw score on 133 points)	(10.90)	(9.63)	(9.95)	(15.33)	(13.80)	(13.20)
Stroop/word reading	47.19	46.88	46.88	47.65	48.06	47.00
(Time in s)	(6.50)	(5.78)	(6.10)	(10.94)	(9.38)	(6.81)
Stroop/word reading	0.38	0.13	0.19	0.18	0.12	0.07
(Corrected errors)	(0.89)	(0.34)	(0.40)	(0.39)	(0.33)	(0.26)
Stroop/colors naming	71.88	67.44	65.56	65.35	66.12	62.73
(Time in s)*	(13.49)	(10.90)	(9.83)	(12.20)	(11.35)	(8.00)
Stroop/colors naming*	1.88	0.75	0.69	1.00	1.18	0.67
(Corrected errors)	(1.78)	(0.78)	(0.95)	(1.06)	(1.13)	(0.98)
Stroop/color-word interference	138.31	116.19	115.06	131.82	116.29	114.20
(Time in s)	(34.96)	(22.98)	(25.62)	(25.02)	(21.20)	(16.84)
Stroop/color-word interference	3.13	1.56	1.06	2.47	2.35	1.67
(Corrected errors)	(2.78)	(1.32)	(1.00)	(2.45)	(2.26)	(1.84)
Stroop/color-word flexibility*	157.31	136.06	131.19	139.59	133.47	127.20
(Time in s)	(25.97)	(22.13)	(29.32)	(19.13)	(24.15)	(21.44)
Stroop/color-word flexibility	3.81	1.50	1.25	1.59	2.41	1.67
(Corrected color errors)*	(2.71)	(1.67)	(1.24)	(1.50)	(2.12)	(1.23)
Trail Making Test Part A	41.35	39.65	34.77	41.59	34.18	32.87
(Time in s)	(12.29)	(11.22)	(8.30)	(13.88)	(12.69)	(7.68)
Trail Making Test Part B	106.63	85.63	89.13	83.71	78.47	76.27
(Time in s)	(34.83)	(16.77)	(22.72)	(17.52)	(17.87)	(11.54)
Symbol Search	24.18	26.18	27.41	27.65	29.00	28.47
(Raw score on 60 points)	(4.86)	(5.82)	(5.96)	(5.29)	(4.06)	(4.72)
Letter-Number Sequencing	9.41	9.71	10.06	9.71	9.76	10.00
(Raw score on 21 points)	(1.94)	(2.14)	(1.43)	(1.53)	(1.99)	(1.51)

*When significant Group X Session interaction (see results section for description)

Figure Captions

Figure 1. Illustration of the dual-task during the training sessions. The odometer shows individualized adaptive feedback for response latency (see text for details).

Figure 2. (A) Mean Reaction Time (ms) and (B) Percentage of correct responses in dual-task training in the three trial types (single-pure, single-mixed and dual-mixed) as a function of the six training sessions in the training group.

Figure 3. (A) Mean Reaction Time (ms) and (B) Percentage of correct responses in the three trial types (single-pure, single-mixed and dual-mixed) in pre-test and post-test sessions in both the control and the training groups.

Figure 4. Percentage of change after training ((post-test – pre-test/pre-test)*100) in the Digit Symbol-Coding test in both the control and the training groups.

Figure 5. Switch cost in the Trail Making Test (Trail B-Trail A/Trail A) in pre-test and post-test sessions in both the control and the training groups.

Figure 6. Percentage of change after training ((pre-test – post-test/pre-test)*100) in time to complete the Flexibility condition of the Stroop test in both the control and the training groups.

Figure 7. Percentage of change in corrected errors during the Stroop Flexibility condition ((Pre-test – Post-test / Pre-test)*100) in both the control and the training groups.

Figure 1


MOYEN
- -
+ +
LENT
RAPIDE
9
Main Gauche
Cercle
Case
Main Droite
Chiffre
Lettre

Figure 2

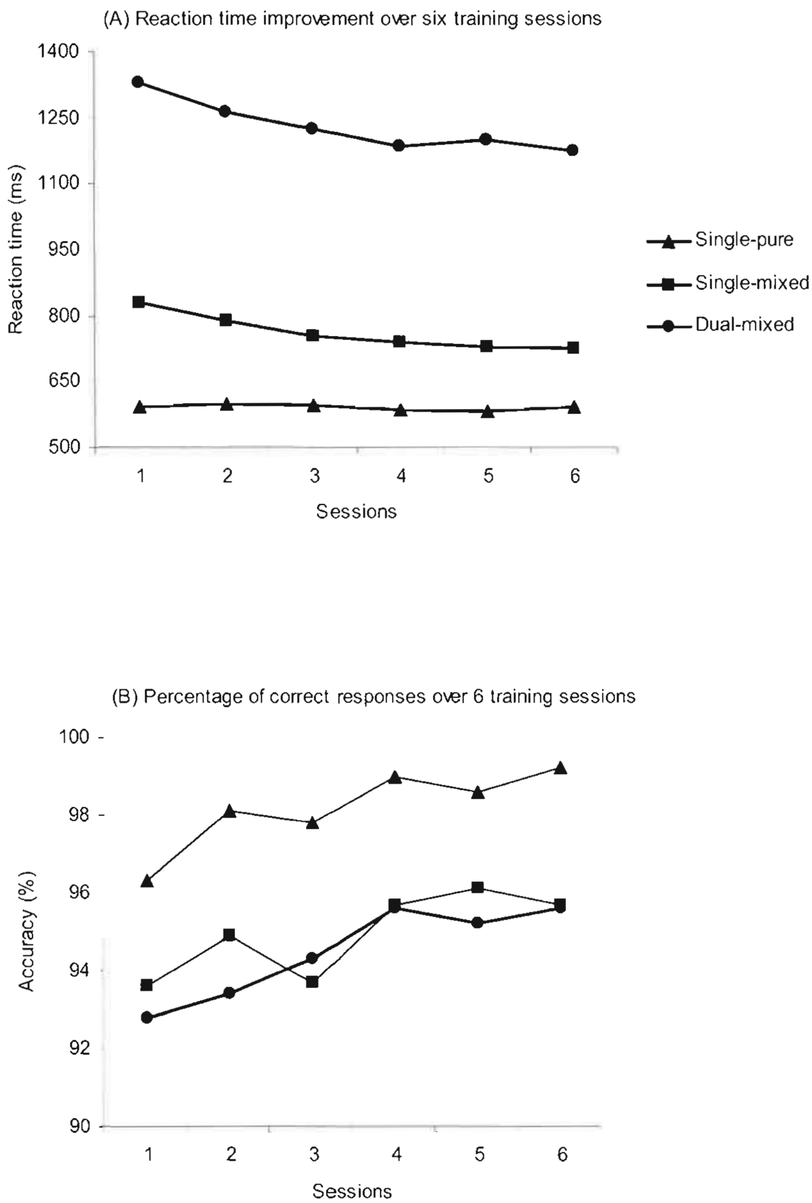
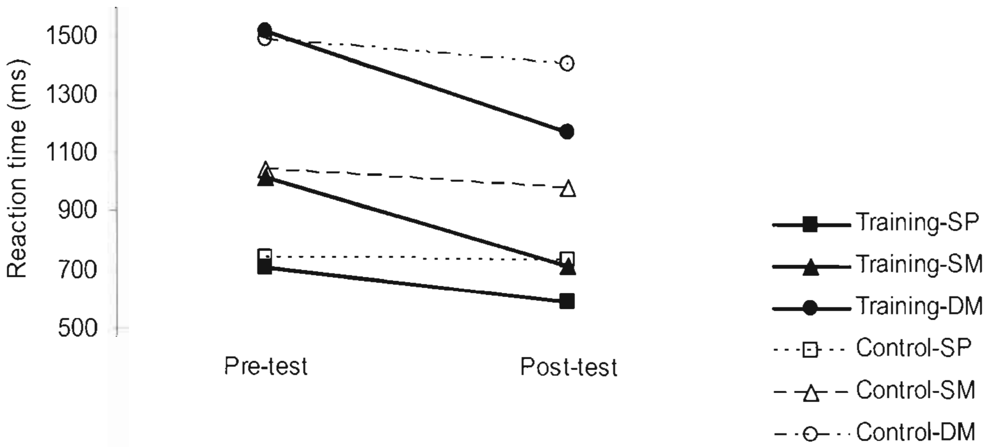

(A) Reaction time improvement over six training sessions
Reaction time (ms)
1400
1250
1100
950
800
650
500
1
2
3
4
5
6
Sessions
Single-pure
Single-mixed
Dual-mixed
(B) Percentage of correct responses over 6 training sessions
Accuracy (%)
100
98
96
94
92
90
1
2
3
4
5
6
Sessions

Figure 3

(A) Reaction time in pre-test and post-test sessions



(B) Percentage of correct responses in pre-test and post-test sessions

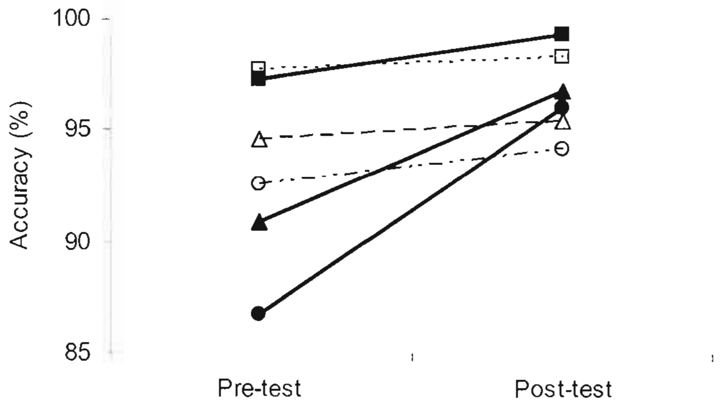


Figure 4

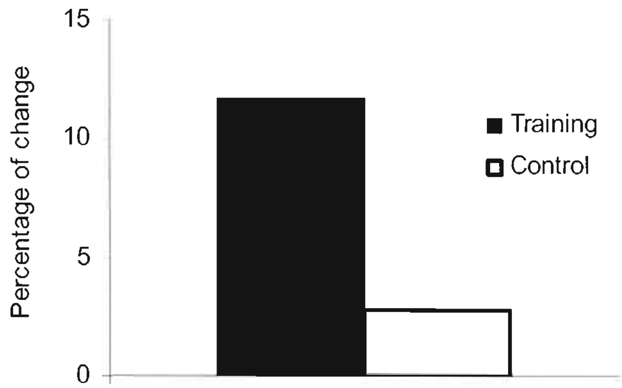


Figure 5

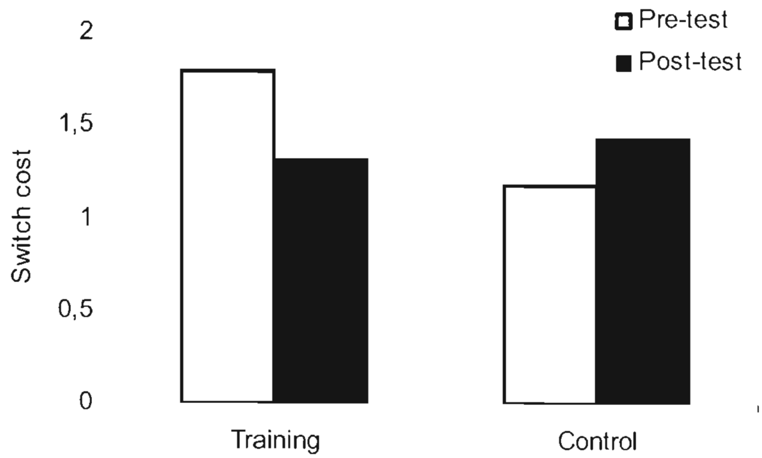


Figure 6

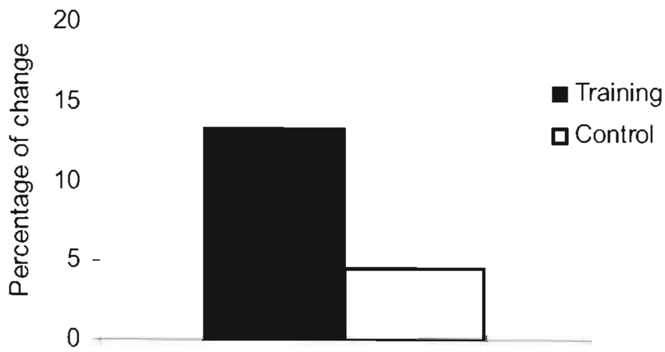
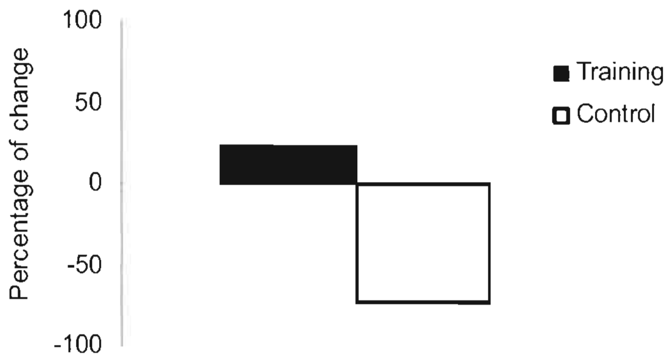


Figure 7



CHAPITRE III

ARTICLE 2

The effects of inhibition training in older and younger adults

The Effects of Inhibition Training in Older and Younger Adults

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Abstract

Recent studies suggest that attention and executive functions can be substantially improved in older and younger adults through computerized cognitive training. However, few of these studies have specifically targeted inhibition, a component of executive control that is impaired with age (Hasher & Zacks, 1988; Lustig, Hasher, & Zacks, 2007; Sweeney, Rosano, Berman, & Luna, 2001). In this study, 28 older adults and 24 younger adults were assigned to computer training or to a control group. The training group completed 6 sessions of training with the Stop-Signal task. Training effects were assessed with an alternative version of the Stop-Signal task and neuropsychological tests targeting inhibition (the Stroop Test and the Hayling Test). The results showed enhanced performance in the Stop-Signal task and the neuropsychological tests after training only for older adults. Moreover, training effects were specific to the inhibition condition of the tasks, which suggests that training with the Stop-Signal paradigm may help improving inhibition control in older adults.

Keywords: Aging, Cognitive training, Inhibition control, Transfer effects, Neuropsychological tests

Word count for the main text = 7, 661 words (26 pages)

The Effects of Inhibition Training in Older and Younger Adults

Inhibition refers to the ability to control and regulate irrelevant information. Deficits in inhibition processing have been proposed as a major player accounting for age-related deficits in a variety of cognitive skills (Hasher & Zacks, 1988; Healey, Campbell, & Hasher, 2008; Lustig, Hasher, & Zacks, 2007; Sweeney, Rosano, Berman, & Luna, 2001). Nevertheless, some studies failed to observe age differences between older and younger adults in cognitive tasks assumed to assess inhibition (For a review, see Kramer & Madden, 2008 and McDowd & Shaw, 2000). Diverging results among studies could be related to the use of different experimental paradigms. In fact, according to some accounts, inhibition is not a unitary construct and multiple inhibitory mechanisms or functions, mediated by different cortical pathways, might be distinctly altered, and at different rates, during normal aging (Andrés, Guerrini, Phillips, & Perfect, 2008; Friendman & Miyake, 2004; Kok, 1999; Kramer, Humphrey, Larish, Logan, & Strayer, 1994; Maylor, Schlaghecken, & Watson, 2005; McCrae & Abrams, 2001; Nigg, 2000; Rush, Barch, & Braver, 2006; Sweeney, Rosano, Berman, & Luna, 2001).

It has been observed that inhibition tasks that require conscious, intentional, and effortful suppression of irrelevant responses and that rely on the integrity of the frontal and prefrontal regions of the cerebral cortex tend to be more affected by normal aging than those that rely on automatic inhibition (Andrés, Guerrini, Phillips, & Perfect, 2008; Kramer, Humphrey, Larish, Logan, & Strayer, 1994). Moreover, Jefferson, Paul, Oxonoff, and Cohen (2006) observed a strong relationship between inhibitory control (using a variant of the Stroop paradigm) and instrumental activities of daily living (IADLs) impairments among older adults at risk for functional decline. These authors suggested that susceptibility to interference while performing instrumental activities (shopping, laundry, financial management and transportation) is more important for the integrity of IADLs than other executive functioning abilities, including planning, sequencing, generation, or working memory.

An important question, raised by Kramer, Humphrey, Larish, Logan, and Strayer (1994), is whether cognitive training interventions can help reversing the age-related inhibitory deficits. Performance improvements on the Stroop color-word task after substantial practice suggest that interference can be decreased in older adults (Davidson, Zacks, & Williams, 2003; Dulaney & Rogers, 1994). Although these results suggest that training can improve inhibition, training benefits were observed on the very same task that was used for training, thus it is unknown whether the benefits could be generalized to untrained inhibition tasks. Moreover, to our knowledge, it has never been observed whether inhibition can be improved with a task other than the Stroop color-word task. One type of inhibition task that is sensitive to age-related differences is the Stop-Signal paradigm. In this task, participants perform a choice reaction time task and must refrain from responding when a specific signal (e.g., a tone) occurs randomly on some trials (about 25%). The overt motor response must be intentionally inhibited by the subject, requiring controlled inhibition processes (Logan, 1994). The Stop-Signal task is an ideal task for testing the effects of cognitive training on inhibition skills given its sensitivity to age-related difference as observed in many studies (Andrés, Guerrini, Phillips, & Perfect, 2008; Bedard et al., 2002; Keys, 2002; Kramer et al., 1994; May & Hasher, 1998; Rush, Barch, & Braver, 2006).

The aim of the present study was to explore whether inhibition control in older adults could be improved after computerized training using the Stop-Signal task. Participants had the instruction to stop an action only when a specific signal occurred (e.g., stop the overt response only when the signal is a high tone and respond if the signal is a low tone). According to Bedard et al. (2002), this task requires selective inhibitory control. This procedure offers the advantage of reproducing typical everyday life situations in which the inhibition of a proponent motor response depends upon the nature of a given signal (e.g. stop a car to a red light and keep driving to a green light).

Another important goal of the present study was to assess whether training with the Stop-Signal task would lead to benefits in untrained tasks as those typically used to assess age-related deficits in inhibition. Training benefits were assessed with an alternative version of the Stop-Signal task, the Stroop Test, and the Hayling Test. Performances in these tests are thought to rely on controlled inhibition processes, executive in nature, that have been shown to be altered by normal aging (Andrés, Guerrini, Phillips, & Perfect, 2008; Andrés & Van der Linden, 2000; Bedard et al., 2002; Belleville, Rouleau, & Van der Linden, 2006; Bielak, Mansueti, Strauss, & Dixon, 2006; Burgess & Shallice, 1996; Collette et al., 2001; Collette, Schmidt, Scherrer, Adam, & Salmon, 2007; Kramer, Humphrey, Larish, Logan, & Strayer, 1994; May & Hasher, 1998; Rush, Barch, & Braver, 2006; Williams, Ponesse, Schachar, Logan, & Tannock, 1999). If the cognitive training with the Stop-Signal paradigm is successful in improving inhibition processing, improvements should also be observed on the Stroop Test and the Hayling Test given that all these tests required inhibition (Brenes, 2003; Dahlin, Nyberg, Bäckman, & Stigsdotter Neely, 2008; Thorndike & Woodworth, 1901). In each test, a control condition not involving inhibition will allow documenting to what extent the improvement is specific to the inhibition condition or rather relies on a general improvement in speed of processing, motivation, or other factors associated to training.

Method

Participants

Twenty-eight older adults and twenty-four younger adults participated in the study. Participants were all right handed francophone community dwelling individuals. The group of older adults was formed by 24 women and 4 men, with mean age of 74 years (SD = 5.26) and a school education level of 13.50 years (SD = 2.44). The group of young adults was composed of 20 women and 4 men, with mean age of 22 years (SD = 2.52) and a school education level of 14.38 years (SD = 1.66). All participants reported good health (on a 5-point scale, the mean score was 4.21 for older adults and 4.17 for younger adults) and none of them had surgery with general anaesthesia within six months prior to testing. They had no history of neurological or psychiatric diseases and none of them were taking medications known to have an influence on cognition.

In a 60-minutes pre-screening session, all participants completed a perceptual screening questionnaire, which served to detect the presence of visual or auditory impairments. Moreover, the Mini Mental State Examination (Folstein, Folstein, & McHugh, 1975) was used to exclude older participants suffering from dementia (mean score of older adults was 29/30, with a range of 27-30). Older adults also completed the Geriatric Depression Scale (Yesavage et al., 1983) in which a mean score of 2.82 (range of 0-9) indicated no sign of depression (cut-off score of 11). Participants' general cognitive abilities were also assessed with a psychometric test battery that included Digit Symbol-Coding (WAIS-III), Digit Span (WAIS-III), Similarities (WAIS-III), Verbal Fluency Test (number of words starting with P-T-L generated in 90 s), and Matrix Reasoning (WAIS-III). Participants' characteristics and performances on the screening tests are shown in Table 1. Results showed similar performances on the screening tests for the training and control groups, as well as an absence of interaction between Age and Group; which suggests that the training and control groups were equivalent on cognitive abilities.

Procedure

The Computer Training Program

A computerized Stop-Signal training program was specifically designed for the purpose of this study (see Figure 1). Participants were seated in a quiet room, in front of a computer (Pentium4) with headphones and performed a 2-choice reaction task consisting of discriminating whether the form appearing on the screen was a circle or a square. A fixation point appeared in the middle of the screen for 1000ms, followed by the stimulus. Participants provided their responses with the « K » or « L » keys of the keyboard with the index and the middle finger of the right hand. Stimulus-response mapping remained on the screen throughout the experiment, to avoid any confusion related to forgetting which key was associated to which stimulus. The 2-choice RT task is referred to as the Go task. The particularity of the selective Stop-Signal paradigm used in this study is that only one of two tone signals that appeared during the Go task indicated that the motor response had to be inhibited. The critical tone signal is called the stop-signal. The tone that had to be ignored is referred to as the non-stop signal. In the present experiment, the non-stop signal indicating that the participant responded normally to the Go task was a low tone (250 Hz). The stop-signal was a high tone (1000 Hz). This selective Stop-Signal task thus required for the participant to discriminate between stop (high tone) and non-stop (low tone) auditory signals. The stop and non-stop auditory signals lasted 500ms. The visual stimuli (square or circle) used in the Go task lasted 1000ms or until the participant provided a response. Participants were told that the auditory signals could occur at different times and they should not wait for the Stop-Signal because it would occur randomly and infrequently.

The Stop-Signal delay (time spent between the apparition of Go and Stop-Signal stimulus) was initially set at 250ms and then was adapted according to the participant's performance. If the participant stopped his answer (successful inhibition), the computer automatically increased the next Stop-Signal delay by 50ms (e.g.: 250ms + 50ms = 300ms), increasing the difficulty of the inhibition task. But if the participant failed to stop or inhibit his action and thus answered to the Go task despite occurrence of the stop-signal, the computer automatically decreased the next Stop-Signal delay by 50ms (e.g.: 300ms – 50 ms = 250ms). Consequently, the inhibition task became easier. This online tracking algorithm (see Logan 1994 for a description of the race model) allows approximately 50% of inhibition accuracy and produces a tie between response execution and response inhibition. Then, the Stop-Signal reaction time (SSRT) is calculated by subtracting the mean Stop-Signal delay (SSd) from the mean Go reaction time (GoRT; reaction time from trials without auditory signals).[7] In a given session, the first block is always excluded from this computation to allow individual adjustment. An alternative Go reaction time (AGoRT) can also be calculated from trials in which the non-stop signal (low tone) occurred. From this AGoRT, an alternative Stop-Signal reaction time (ASSRT) could also be computed (ASSRT = AGoRT – SSd). Percentage of inhibition responses given for the Stop-Signal (%SS), percentage of trials completed given for the non-stop signal (%NSS), and percentage of correct Go responses (%Go) were also calculated.

An updated individualized performance feedback (see Bherer and al., 2005, and Kramer, Larish, & Strayer, 1995, on the importance of feedback on training studies) was also provided. The feedback took the form of an odometer presented on

[7] SSRT = GoRT - SSd

the left upside part of the computer screen. The needle of the odometer moved according to response speed in the Go task and the color of the left portion of the odometer indicated to the participant whether the performance was appropriate. The left portion of the odometer appeared in yellow, purple, or blue when the mean RT of the last 5 trials were respectively: higher than the mean RT for the entire block multiplied by a ratio of 1.8; equal or smaller than the mean of the block divided by a ratio of 1.8; or in between these two criteria. This calculation procedure, not described to the participants, was intended to encourage participants to avoid slowing down responses and thus facilitating the stopping task. On the other hand, participants were also asked to avoid responding too quickly, which could jeopardize stopping the action. Thus, a medium speed was promoted, similarly to driving rules in real life situations. Moreover, a word-feedback « incorrect answer » appeared on the screen every time an error was made in the Go task.

Participants from the training group undertook six sessions of the inhibition training lasting about 45 minutes. Participants completed one session per day and had to complete the sixth session within a three-week delay. The Stop-Signal task included 8 experimental blocks of 32 trials each (total of 256 trials). Each trial was presented every 4 second. The Stop-Signal occurred on 19% of the Go trials. The low tone (non-stop signal) also occurred on 19% of the Go trials.

Pre-test and Post-test Measures

After the pre-screening session (described above), participants were randomly assigned to either the training or the control groups. All participants completed the same pre-test and post-test sessions, but only the training group completed the 6 training sessions. In a 90-minute pre-test session, participants completed the neuropsychological tests (Hayling Test and the modified Stroop Color-Word Test) and two versions of the Stop-Signal task (the training and the transfer version). Participants of both training and control groups completed a post-test session after the 4-week delay. Post-test session was identical to the pre-test session.

Hayling Test. The test involves two conditions: automatic and inhibition. Each condition involves 2 practice sentences followed by 15 short sentences in which the last word is missing. In the automatic condition, the participant must complete each sentence by providing an appropriate word as fast as possible. In the inhibition condition, the participant must complete the sentence with a word that is completely unrelated to the sentence (see Belleville, Rouleau & Van der Linden, 2006; Burgess & Shallice 1996). Response latencies were recorded from the last word told by the experimenter, who read the sentence, to the response provided aloud by the participant. In the inhibition condition, error scores were computed following these criteria: 0 for an unrelated response, 1 for an antonym or a semantically related word, and 3 when the sentence was completed with the suitable word (e.g., Prisoners have escaped from ____? Prison).

The modified Stroop Color-Word Test. This test was originally proposed by Bohnen, Jolles, and Twijnstra (1992 and see Chatelois et al., 1996). The test involves four different conditions, each including 100 stimuli (10 items per line) printed on a 21.5 x 28 cm sheet of paper. In the word reading condition, participants must read as fast as possible words printed in black ink that represent four colors. In the color naming condition, participants must name the colors of rectangles printed in red, green, blue, and yellow. In the color-word interference condition, color-words are printed in a color differing from their meaning (e.g., the word blue printed in green) and participants must name the color of the printing while ignoring the meaning of the word. In the color-word flexibility condition, participants perform a color-word interference condition, except that printed rectangles are randomly placed around 20 color-words out of the 100 items. A rectangle indicated to the participant to read the word instead of naming its color. This fourth condition adds a switching component to the classical Stroop task by asking participant to alternate from naming the color of the word to reading the word. Participants had to complete the four conditions as fast as possible. Variables of interest were the time taken to complete each of the four conditions as well as the number of errors corrected spontaneously by the participants (corrected errors).

Baseline performance in the Stop-Signal tasks. To assess the effect of training on Stop-Signal task performances, baseline performance was recorded with the Auditory Stop-Signal task, used for training, as well as with a transfer task. A Visual Stop-Signal task was used as a cross-modality transfer task. Participants first completed the Auditory Stop-Signal task (as previously described), followed by the Visual Stop-Signal task. In each task, thirty-two trials were performed to allow familiarization with the Go task only (practice block without Stop-Signal). Then, participants completed one practice block of the Stop-Signal task (32 trials) and seven experimental blocks of 32 trials (total of 224 trials), in each task modality.

The procedure of the Visual Stop-Signal task was similar to the auditory Stop-Signal Task described above. First, participant completed a choice reaction-time task (the Go task) which requires indicating whether an arrow, appearing in the middle of the screen, pointed to the left (←) or to the right (→). Participants provided their responses by pushing down the « A » and « S » keys on the keyboard with the middle and the index finger of left hand. Stimulus-response mapping remained on the screen throughout the experiment, to avoid any confound related to forgetting which key is associated to which stimulus. One block of trials was done to allow familiarization with the Go task (practice block without Stop-Signal). Then, instructions about the Stop-Signal procedure were introduced. Then participants completed the Go task but had to avoid responding (withhold key press) when a red flag was presented during the trial. The Stop-Signal was selective because participant had to complete the Go task normally when the flag was green (the non-stop signal). This task is analogue to driving as people should stop their car when the light is red and continue on a green light.

Results

Two sets of analyses were performed. The first set of analysis explored participants' performances during the six computerized training sessions, in order to assess training effects. A second set of analyses compared pre-test vs. post-test performances on the Stop-Signal tasks, as well as on the neuropsychological tests. In these analyses, comparing training and control participants allowed us to assess training effects rather than mere test-retest effects.

Training Sessions

Variables of interest are presented in Table 2. ANOVAs were performed with Age (Older vs. Younger) as between-subject factor and Session as within-subject factor (Sessions 1 to 6). Follow-up analyses were performed separately for each age group. In the case of a significant interaction with more than two levels of a repeated-factor (e.g., 6 training sessions), repeated-contrasts were performed to compare two consecutive levels of a repeated factor. Statistical analyses were performed with SPSS (SPSS Inc.). Alpha levels for significant effects were set at .05 and adjusted alpha levels (Huynh-Feldt) were used when the Mauchly's test of sphericity was significant (SPSS, 2003). Effect sizes (η^2) are also reported.

Reaction time analyses

GoRTs were recorded in the choice reaction-time task (discrimination between a square and a circle) on trials without an auditory signal. In GoRTs, a main effect of Age was obtained, $F(1, 24) = 19.02$, $p < .001$, $\eta^2 = .44$. Older adults were significantly slower overall than younger adults (Older; 662ms, Younger; 411ms). No main effects of Session, $F(5, 120) = 1.13$, *ns,* or interactions between Session and Age, $F(5, 120) < 1$, *ns,* were observed. Reaction times to the imperative signal (square and circle) on trials in which the non-stop signals (low tone) occurred were also analyzed (*Alternative Go Reaction Time Analyses,* AGoRT). ANOVAs performed with AGoRTs showed a main effect of Age, $F(1, 24) = 22.70$, $p < .001$, $\eta^2 = .49$. Older adults were slower overall than younger adults (Older; 766 ms, Younger; 461 ms). Training lead to a decrease in AGoRTs as indicated by a main effect of Session, $F(5, 120) = 4.27$, $p < .01$, $\eta^2 = .15$. Repeated-contrasts indicated that AGoRTs became globally faster from Session 1 to Session 2, $F(1, 24) = 7.62$, $p < .01$, $\eta^2 = .24$, with no further improvement in subsequent sessions. A significant interaction between Age and Session was also observed, $F(5, 120) = 2.43$, $p < .05$, $\eta^2 = .09$. Follow-up analyses indicated a significant improvement in older adults, $F(5, 65) = 6.10$, $p < .001$, $\eta^2 = .32$, from Session 1 to Session 2 only, $F(1, 13) = 5.72$, $p < .05$, $\eta^2 = .31$. However, AGoRTs did not improve in younger adults, $F(5, 55) < 1$, *ns*.

Stop-Signal Reaction Time (SSRT) was calculated by subtracting the mean Stop-Signal delay (SSd) from the mean GoRT (SSRT = GoRT – SSd). ANOVAs on SSRT did not show a main effect of Age, $F(1, 24) = 3.01$, $p = .096$, $\eta^2 = .11$, Session, $F(5, 120) = 1.94$, *ns*, or an interaction between Age and Session, $F(5, 120) = 2.07$, *ns*. Alternative Stop-Signal Reaction Time (ASSRT) was calculated by subtracting the mean Stop-Signal delay from the Alternative GoRT (ASSRT = AGoRT – SSd). ASSRTs were similar in older (371ms) and younger adults (354ms) with no main effect of Age, $F(1, 24) < 1$, *ns*. However, ASSRTs improved with Session, $F(5, 120) = 7.96$, $p < .001$, $\eta^2 = .25$, (from session 1 to session 2 only, $F(1, 24) = 12.71$, $p < .005$, $\eta^2 = .35$), and the effect differed among group as indicated by an Age by

Session interaction, $F(5, 120) = 6.61$, $p < .001$, $\eta^2 = .22$. The improvement was significant in older adults, $F(5, 65) = 13.72$, $p < .001$, $\eta^2 = .51$, between sessions 1 and 2, $F(1, 13) = 13.46$, $p < .005$, $\eta^2 = .51$, whereas ASSRT did not improve with training in younger adults, $F(5, 55) < 1$, *ns*.

Accuracy Analyses

A main effect of Age, $F(1, 24) = 6.84$, $p < .05$, $\eta^2 = .22$, was observed on the percentage of inhibition responses when the Stop-Signal occured (%SS). Older adults inhibited more often the overt response than younger adults (Older; 50%, Younger; 40%). Again, a main effect of Session was observed, $F(5, 120) = 3.11$, $p < .05$, $\eta^2 = .12$. Results of repeated-contrasts between the six sessions were not significant (p >.05, *ns*), but polynomial-contrasts revealed a significant linear effect, $F(1, 24) = 4.69$, $p < .05$, $\eta^2 = .16$, indicating a general decrease of inhibition accuracy from training sessions 1 to 6. Yet, there was no interaction between Session and Age, $F(5, 120) < 1$, *ns.* Analyses on the percentage of trials completed for the non-stop signal (%NSS) indicated no effect of Age, $F(1, 24) = 3.72$, $p = .066$, $\eta^2 = .13$, and no improvement with Session, $F(5, 120) = 1.98$, *ns,* or interaction between Session and Age, $F(5, 120) < 1$, *ns.* In the analyses performed on the percentage of correct Go responses (%Go), older adults performed betters than younger adults (Older = 98%; Younger = 96%), $F(1, 24) = 7.00$, $p < .05$, $\eta^2 = .23$, and there was no change with Session, $F(5, 120) = 1.92$, *ns*, or interaction between Session and Age, $F(5, 120) = 1.56$, *ns*.

Pre-test Versus Post-test Analyses

This section reports results observed from pre-test to post-test sessions in the training group compared to the performance of the control group, which did not engage in Stop-Signal training. Data from the auditory Stop-Signal task (training task) are presented first, followed by the results obtained in the visual Stop-Signal task, and the neuropsychological tests. Variables of interest are presented in Table 3 and 4. Data were analysed with ANOVAs involving two between-subject factors, Age (Older vs. Younger) and Group (Training vs. Control), and one within-subject factor, Session (pre-test vs. post-test). Significant interactions between these factors were decomposed with simple-effects.

Auditory Stop-Signal Task

Reaction time analyses. GoRT was slower in older adults compared to younger adults (Older; 685 ms, Younger; 434 ms), $F(1, 48) = 59.26$, $p < .001$, $\eta^2 = .55$. No main effect of Session or interaction involving Session, Age or Group, $F(1, 48) < 1$, *ns,* was observed. Age-related differences were also observed with AGoRTs, $F(1, 48) = 53.04$, $p < .001$, $\eta^2 = .53$, (Older; 841 ms, Younger; 502 ms). AGoRTs improved with training, $F(1, 48) = 6.43$, $p < .05$, $\eta^2 = .12$, and this improvement was different between experimental groups as indicated by a Group X Session interaction $F(1, 48) = 4.14$, $p < .05$, $\eta^2 = .08$. Simple-effects indicated a significant decrease in AGoRT in the training group (694ms - 604ms), $F(1, 50) = 11.12$, $p < .005$, which was not observed in the control group (699ms - 689ms), $F(1, 50) < 1$, *ns*. However, the

Age X Session interaction, $F(1, 48) < 1$, *ns*, and the Age X Group X Session interaction failed to reach significance, $F(1, 48) = 2.27$, *ns*.

There were no age-related differences in SSRT (older; 320ms, younger; 317ms), $F(1, 48) < 1$, *ns*.[8] SSRTs (see Figure 2) decreased from pre-test to post-test, $F(1, 48) = 10.95$, $p < .005$, $\eta^2 = .19$. Decreases in SSRT were also larger in older than in younger adults, as indicated by an interaction between Age and Session, $F(1, 48) = 8.97$, $p < .005$, $\eta^2 = .16$. Simple-effects showed an improvement in older adults (351ms to 289ms), $F(1, 50) = 19.41$, $p < .001$, while performances remained unchanged in younger adults (318ms to 315ms), $F(1, 50) < 1$, *ns*. The Group X Session interaction reached significant level, $F(1, 48) = 4.54$, $p < .05$, $\eta^2 = .09$, due to significant improvement in the training group (337ms to 283ms), $F(1, 50) = 14.20$, $p < .001$, which was not observed in the control group (333ms to 321ms), $F(1, 50) < 1$, *ns*. Importantly, the level of improvement was independent of age as indicated by the absence of an Age X Group X Session interaction, $F(1, 48) = 2.38$, *ns*. A similar pattern of results was observed with ASSRT, with a significant main effect of Age, $F(1, 48) = 7.07$, $p < .01$, $\eta^2 = .13$, (Older; 475 ms, Younger; 385 ms)[9] and Session, $F(1, 48) = 22.33$, $p < .001$, $\eta^2 = .32$, along with a Group X Session interaction, $F(1, 48) = 12.49$, $p < .001$, $\eta^2 = .21$, and an Age X Session interaction, $F(1, 48) = 5.71$, p

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[8] An ANOVA was performed at baseline (pre-test session only) and results showed also no Age-related differences in SSRT, $F(1, 50) = 1.73$, *ns*. Stop-Signal Reaction Time (SSRT) at baseline was statistically equivalent in older (351ms) and younger adults (318ms).

[9] An ANOVA (pre-test session only) also showed Age-related differences in ASSRT in favor of younger adults (404ms) compared to older adults (531ms), $F(1, 50) = 13.68$, $p < .001$, $\eta^2 = .22$.

$< .05$, $\eta^2 = .11$. Moreover, the 3-way interaction reached significance, Age x Group x Session, $F(1, 48) = 3.94$, $p < .05$, $\eta^2 = .08$. In older adults, a main effect of Session, $F(1, 26) = 17.07$, $p < .001$, $\eta^2 = .40$, as well as a Group X Session interaction, $F(1, 26) = 10.27$, $p < .005$, $\eta^2 = .28$, indicated that the training group showed a significant decrease in ASSRT after training (538ms - 340ms), $F(1, 26) = 26.92$, $p < .001$, which was not the case for the control group (524ms - 499ms), $F(1, 26) < 1$, *ns*. In younger adults, the main effect of Session was significant, $F(1, 22) = 8.94$, $p < .01$, $\eta^2 = .29$, but the interaction between Session and Group did not reach significance, $F(1, 22) = 3.94$, $p = .06$, $\eta^2 = .15$.

Accuracy Analyses. Percentage of inhibition responses when the Stop-Signal (%SS) occurred showed a main effect for Age, $F(1, 48) = 17.79$, $p < .001$, $\eta^2 = .27$. Older adults inhibited more often the overt response than younger adults (Older; 52%, Younger; 41%). There was no effect of Session, $F(1, 48) = 1.57$, *ns*, Group x Session interaction, $F(1, 48) = 2.34$, *ns*, or 3-way interaction, $F(1, 48) < 1$, *ns*. Percentage of trials completed when the non-stop signal (%NSS) occurred showed no main effect of Age, $F(1, 48) = 1.61$, *ns*. A main effect of Session was obtained (99.95 to 99.97%), $F(1, 48) = 5.86$, $p < 0.05$, $\eta^2 = .11$, but this effect was equivalent among groups, Session X Group, $F(1, 48) = 1.19$, *ns*, 3-way, $F(1, 48) < 1$, *ns*. The percentage of correct Go responses (%Go), did not differ between Age groups, $F(1, 48) = 2.85$, $p = 0.10$, $\eta^2 = .06$ or Session, $F(1.48) < 1$, *ns*, but an interaction between Session and

Age was observed, $F(1, 48) = 14.42$, $p < 0.01$, $\eta^2 = .23$. Simple-effects analyses indicated an improvement of Go accuracy after training in older adults (97% to 99%), $F(1, 50) = 7.34$, $p < .01$, and a decrease in younger adults (98% to 96%), $F(1, 50) = 6.97$, $p < .01$. Importantly, the Session X Group, $F(1.48) < 1$, *ns*, and the Session X Group X Age interactions, $F(1.48) = 2.02$, *ns*, did not reach significant levels.

Visual Stop-Signal task

Reaction time analyses. An ANOVA on SSRT showed no main effect of Age, $F(1, 48) = 2.35$, *ns*.[10] Main effects of Age, in favor on younger adults, were observed on ASSRTs[11], $F(1, 48) = 29.98$, $p < .001$, $\eta^2 = .38$, GoRT, $F(1, 48) = 39.76$, $p < .001$, $\eta^2 = .45$, and AGoRT, $F(1, 48) = 61.34$, $p < .001$, $\eta^2 = .56$. None of these variables showed a main effect of Session or an interaction involving Session, Age, or Group ($p > .05$, *ns*).

Accuracy Analyses. Percentage of inhibition responses when the Stop-Signal (%SS) occurred showed a main effect of Age, $F(1, 48) = 9.47$, $p < .005$, $\eta^2 = .17$, (Older; 51%, Younger; 45%). A main effect of Group was also observed, $F(1, 48) = 5.48$, $p < .05$, $\eta^2 = .10$. The control group inhibited more often the overt response than the training group (Training group; 46%, Control group; 51%). A main effect of Session was obtained, $F(1, 48) = 3.97$, $p < .05$, $\eta^2 = .08$, but interactions between

[10] An ANOVA performed at baseline (pre-test session only) showed Age-related differences in SSRT in favor of younger adults (279ms) compared to older adults (312ms), $F(1, 50) = 5.55$, $p < .05$, $\eta^2 = .10$.

[11] An ANOVA performed at baseline (pre-test session only) showed also Age-related differences in ASSRT in favor of younger adults (321ms) compared to older adults (438ms), $F(1, 50) = 34.92$, $p < .001$, $\eta^2 = .41$.

Session, Group, and Age were not observed, $F(1,48) < 1$, *ns*. For all the other accuracy indicators (%NSS, %G0), no main effect of Age was observed, neither was the interaction between Age, Session, and Group, $F(1,48) < 1$, *ns*.

Neuropsychological Tests

Age-related differences have been well documented in all clinical tests used in the present study (see Lezak, Howieson, & Loring, 2004) and this has been interpreted as evidence of age-related impairments in executive and attentional control functions. Age-related differences can be observed in all test conditions, including non-executive conditions that do not assess attentional control and inhibition. This can hinder the assessment of specific transfer effects. For this reason, analyses on neuropsychological test performances were performed separately for the two age groups. In each age group, the effect of training was assessed by comparing improvement from pre-test to post-test sessions in the training and the control groups. The ANOVA model included Group (training and control) as between-subject factor and Session (pre-test and post-test) as within-subject factor. Significant interactions between these factors were decomposed with simple-effects. Results are presented in Table 4. Only significant interactions between Group and Session are detailed here.

In older adults, positive effects of training (Group X Session interaction) were observed for the Hayling Test (errors) and in the fourth condition of the Stroop Color Word Test (Flexibility). Clinical neuropsychological tests sometimes show large interindividual differences in older adults, which could produce confounding effects (Lezak, Howieson, & Loring, 2004). For this reason, results were analyzed with raw data, along with percentage scores of improvement that take into account baseline levels of performance.

For the Hayling Test, a main effect of Session was observed on the time to complete the automatic condition, $F(1, 26) = 8.82$, $p < .01$, $\eta^2 = .25$, but the effect was larger in the inhibition condition, $F(1, 26) = 29.37$, $p < .001$, $\eta^2 = .53$. The Group X Session interaction did not reach significance (p >.05, *ns*). However, the number of errors produced in the inhibition condition showed a significant effect of Session, $F(1, 26) = 27.47$, $p < .001$, $\eta^2 = .51$, and a Group X Session interaction, $F(1, 26) = 4.61$, $p < .05$, $\eta^2 = .15$, due to a larger improvement between pre-test and post-test in the training group, $F(1, 26) = 27.30$, $p < .001$, compared to the control group, $F(1, 26) = 4.78$, $p < .05$. An ANOVA performed on the percentage of change after training ((pre-test + 1) – (post-test + 1) / (Pre-test + 1)*100) allowed to confirm that even after controlling for baseline levels of performance, the improvement in number of errors produced was larger in the training group compared to the control group, $F(1, 26) = 6.63$, $p < .05$, $\eta^2 = .20$ (see Figure 4).

For the Stroop Test[12], there was no significant Session effect or interaction between Group and Session in the word reading and in the color naming conditions (p >.05, *ns*). On the interference condition, the Session effect was significant, $F(1, 25) = 39.96$, $p < .001$, $\eta^2 = .62$, but there was no interaction between Group and Session,

[12] Data were excluded for one participant from the control group due to abnormal performance in the Stroop test. The participant performed normally at all other tests.

$F(1, 25) < 1$, *ns*. However, the flexibility condition showed a main effect of Session, $F(1, 25) = 27.20$, $p < .001$, $\eta^2 = .52$, as well as a Group X Session interaction, $F(1, 25) = 7.66$, $p < .01$, $\eta^2 = .24$. This was due to a significant improvement in the time to complete the test for the training group, $F(1, 25) = 33.09$, $p < .001$, which was not observed in the control group, $F(1, 25) = 2.89$, *ns*. As can be seen in Figure 5a, percentage of change (Pre-test – post-test/ pre-test*100) also showed larger variations in the training group compared to control participants, $F(1, 25) = 8.52$, $p < .01$, $\eta^2 = .25$. A significant Group X Session interaction was also observed for corrected errors, $F(1, 25) = 5.54$, $p < .05$, $\eta^2 = .18$. Simple-effects indicated that the training group committed less errors after training, $F(1, 25) = 5.45$, $p < .05$, while errors produced by the control group did not change from pre-test to post-test, $F(1, 25) = 1.04$, *ns*. The benefit of training on corrected errors was also confirmed by a larger percentage of change ((pre-test + 1) – (post-test + 1) / (Pre-test + 1)*100) in the training group, $F(1, 25) = 6.36$, $p < .05$, $\eta^2 = .20$ (see Figure 5b).

In younger adults, main effects of Session were observed on time to complete the inhibition condition of the Hayling, $F(1, 22) = 5.11$, $p < .05$, $\eta^2 = .19$, the Stroop color naming condition, $F(1, 22) = 17.18$, $p < .001$, $\eta^2 = .44$, the Stroop interference condition, $F(1, 22) = 20.19$, $p < .001$, $\eta^2 = .48$, and the Stroop flexibility condition, $F(1, 22) = 27.86$, $p < .001$, $\eta^2 = .56$. But more importantly, there was no interactions between Session and Group for the Hayling Test or for the Stroop Test (p >.05, *ns*).

Equivalent changes from pre-test to post-test among groups suggests that improvements in performance do not exceed test-retest effect in younger adults.

Discussion

The goal of the present study was to assess the extent to which training can improve inhibition control in older and younger adults. Older and younger adults performed six training sessions with the Stop-Signal paradigm that requires inhibiting prepotent responses when a stop-signal occurs (and ignore the non-stop signal). Training effects were assessed at pre and post-tests on the training task. Generalization of learning was assessed with an alternative version of the Stop-Signal task and with neuropsychological tests that are frequently used to assess inhibition in older adult populations. The results reported here showed that inhibition can be improved after cognitive training, as observed with shorter Stop-Signal reaction times in the training group. In older adults that completed the training program, transfer effects were also observed as assessed with neuropsychological tests of inhibition (Stroop Test and Hayling Test). Age-related differences in inhibition are discussed first, followed by a discussion on the training effects observed in the present study.

Results of the present study showed age-related deficits in inhibition in the Stroop Test and the Hayling Test, as previously reported in many studies (e.g.; Andrés, Guerrini, Phillips, & Perfect, 2008; Andrés & Van der Linden, 2000; Belleville, Rouleau, & Van der Linden, 2006; Bielak, Mansueti, Strauss, & Dixon, 2006; Burgess & Shallice, 1996; Collette, Schmidt, Scherrer, Adam, & Salmon, 2007; May & Hasher, 1998; Rush, Barch, & Braver, 2006). However, our results did not show age-related differences at baseline on the auditory Stop-Signal task. This result differs from past studies showing age-related differences in inhibition with the Stop-Signal task (Andrés, Guerrini, Phillips, & Perfect, 2008, Bedard et al., 2002; Keys, 2002; Kramer, Humphrey, Larish, Logan, & Strayer, 1994; May & Hasher, 1998; Rush, Barch, & Braver, 2006). The absence of age-related differences in the present study might be due to poor performances in the group of younger adults that showed slower SSRTs than what was reported in previous studies (e.g., in Bedard et al. 2002). Other studies also reported slower SSRTs in younger adults compared to older adults (Williams, Ponesse, Schachar, Logan, & Tannock, 1999) in the Stop-Signal task using auditory stimuli. To our knowledge, the present study was the first to compare older and younger adults' performances on a visual version of the Stop-Signal task. An age-related difference at baseline in visual SSRT was observed in favor of younger adults (279ms) compared to older adults (312ms). Further studies might help explaining why age-related differences emerged in the visual task but not in the auditory task. Previous studies on the effect of Stop-Signal modality in younger adults alleged that stopping results are better in the auditory modality (faster SSRT) due to differences in perceptual processes and shorter neural pathways for sound perception (see Van der Schoot, Licht, Horsley, & Sergeant, 2005). Our results do not confirm those of Van der Schoot et al. (2005) as the visual SSRT results seem shorter (312ms in older adults and 279ms in younger adults) than the auditory SSRT results (351ms in older adults and 318ms in younger adults). However, task presentation was not counterbalanced in the present study; the auditory Stop-Signal task was always accomplished first, followed by the visual Stop-Signal task for all participants. This was done so because with a small sample of participants, counterbalancing could have led to spurious effects not related to training. Be that as it may, better performances observed in all groups in the visual task might be due to familiarization with the tasks and procedure. Importantly for our concern, this effect did not differ with age and remained unchanged after training.

Age-related differences were observed in the present study on the Alternative Stop-Signal Reaction Time in both modality conditions. ASSRT was calculated from Go trials in which the non-stop signal was presented (AGoRT – SSd = ASSRT). This differs from the SSRT calculation that uses trials without any stop or non-stop signal (GoRT – SSd = SSRT). Thus, ASSRT calculation takes into account the time taken by participants to choose the appropriate response between two alternatives and the decision process as to whether the response should be inhibited or not. This condition might be more demanding in terms of controlled inhibitory mechanisms since the participants engaged in monitoring for the potential need to inhibit his response and discriminating the signal that occurred while preparing to respond. This situation shares similarities with a dual-task condition and most likely involves a great deal of attentional control, which is known to decline during the course of normal aging (Kramer & Madden, 2008).

The major goal of this study was to assess whether training with the Stop-Signal paradigm would improve controlled inhibition and if the improvement would be the same for older and younger adults. The results showed a significant improvement in inhibition speed after training, as indicated by the reduction in SSRTs and to a greater extent in ASSRTs. This was not observed in the control groups. Thus, the training program seems to have enhanced inhibition control. Note that training did not improve GoRT performances, which is not surprising as participants were encouraged to avoid slowing their responses or to try responding so fast that it would jeopardize stopping the action. Furthermore, the achievement of a medium speed was promoted via an individualized adaptive feedback in real-time (odometer). This condition could be compared to driving a car through an intersection where the driver should reduce speed in case he must suddenly stop the vehicle. Importantly, while feedback was provided to both older and younger adults, to adjust response speed so that achieving an appropriate rate of inhibition responses was possible, the training program led to enhanced performances in older adults only. This suggests that cognitive training is an efficient way to enhance inhibition of speeded prepotent motor responses in older adults.

The results of the present study also showed training benefits that generalized to some extent to untrained tasks of inhibition. In fact, improvements in test performances were observed after training in older adults. It was observed that the number of errors committed in the inhibition condition of the Hayling Test and in the flexibility or switching condition of the Stroop Test declined after training in the training group more so than in the control group of older adults. Trained participants were also faster to complete the test after training. Our training thus seems to have improved inhibition and switching skills, which is not surprising given the selective component involved in the Stop-Signal task used in the present study. Kramer, Humphrey, Larish, Logan, and Strayer (1994) pointed out the dual-task nature of the classical stopping paradigm, as the task requires monitoring of an auditory signal, while responding to the visual stimulus. In addition, the flexibility condition of the modified-Stroop Test that was used in the present study shares some similarities with the Stop-Signal task. In fact, both the selective Stop-Signal and the modified Stroop Test involved switching skills, as a cue occurring randomly indicated to inhibit the automatic task (not reading the word or not responding to the imperative task) or to respond to the automatic task. Generalization to untrained tasks after training for attentional control has been observed in previous studies with older adult participants (Ball et al., 2002; Bherer et al., 2005, 2008; Kramer et al., 1995, 1999). For instance, Bugos, Perlstein, McCrae, Brophy, and Bedenbaugh (2007) recently evaluated the role of musical instruction training in older adults. The training group showed significantly improved performances on the Trail Making Test (including the flexibility condition) and the Digit Symbol Test. Findings from the present study further show that inhibition control is also manageable to training and that benefits can generalize to untrained inhibition tasks.

Recent theoretical account on inhibition formulated by Lustig, Hasher, & Zacks (2007; see also Hasher & Zacks, 1988) can be useful to appreciate the implication of the present findings. The authors suggest three functions of inhibition; access, deletion, and restrain. According to them, inhibition processes control *access to attention's focus, delete irrelevant information from attention and suppressing or* *restraining strong but inappropriate responses*. Lustig et al. (2007) suggest that the Stop-Signal task requires *restraining a strong response. The* classical Stroop task would involve *access* and *restrain* functions as *participants must prevent from reading the word and if this fails, they may have to restrain themselves from responding by naming the color associated to its meaning.* The modified-Stroop condition used in the present study, and that showed the greater transfer effect, shared more similarities with the Stop-Signal paradigm because the participant must await a signal (or the absence of signal) in order to decide whether to restrain a strong response or not. The Hayling Test also has this decision component in common with the other inhibition tests since participants must wait until the sentence has been read before to determining which word would be an appropriate response. In the Hayling Test, the participant must prevent the automatic last word completing the sentence to gain access to consciousness and restrain it, if the access control fails. The improvement observed in these 3 tasks, including the untrained tasks, after training suggests that the ability to restrain a strong response has been improved.

It is important to emphasize that the effect of training, and its generalization to untrained tasks, was specific to the task condition that involved controlled inhibition. There was no general benefit of training in task conditions not involving inhibition, such as the color naming condition of the Stroop for example. The effect of transfer to untrained tasks after training or learning could be conceptualized as a continuum of situations more or less dissimilar to the initial knowledge (Willis, 2001). Transfer could be classified in some dimensions as the temporal context, the functional context, and the modality of the tasks (Barnett & Ceci, 2002; Zelinski, 2008). Based on this classification, the transfer effects reported here would be considered near transfer effects on both the temporal spectrum (transfer assessed testing was immediately after training) and the functional spectrum (similar or common attention functions seem related the training task and the neuropsychological transfer tasks). On the modality spectrum, benefits after training on an auditory task were observed in both an auditory inhibition task (Hayling Test) and a visual inhibition task (the Stroop Test). It thus seems that to some extent, cross-modality transfer could be expected after computerized training. Substantial cross-modality transfer effects have also been observed after dual-task training in older and younger adults in previous studies (Bherer et al., 2005; 2008).

It has been argued that transfer effects after training would more likely emerge when learning entails conscious and abstract general principles and strategies rather than in surface or automatic learning following repetitive learning (Barnett & Ceci, 2002, Willis, 2001, Salomon & Perkins, 1989). Cattel (1963) stated that the human ability to extract general principles of experience learning and to apply it to new situations would promote adaptation and evolution of human specie. However, perhaps not all learning skills need to involve conscious strategies for the benefits of learning to transfer to new situations (e.g. children development learning). Further studies in aging research would be required to conceptualize transfer effects, to create training tasks and paradigms which would increase the likelihood of transfer effects and generalization to everyday situations in order to enhance and maintain older adults' quality of life.

In sum, the results reported here suggest that inhibition control can be improved in older adults after computerized training and that the benefits can be observed in clinical neuropsychological tests of attentional control. Inhibition processing has been proposed as a major player accounting for age-related deficits in a variety of cognitive skills (Hasher & Zacks, 1988; Lustig, Hasher, & Zacks, 2007) and related to the integrity of instrumental activities of daily living (Boyle, Paul, Moser, & Cohen, 2004; Jefferson, Paul, Oxonoff, & Cohen, 2006). As stated by Kramer, Humphrey, Larish, Logan, and Strayer (1994), finding the best ways to improve inhibitory functions in the elderly through training and adaptive interventions remains an important issue for future research.

References

Andrés, P., Guerrini, C., Phillips, L. H., & Perfect, T. J. (2008). Differential effects of aging on executive and automatic inhibition. *Developmental Neuropsychology, 33*, 101-123.

Andrés, P., & Van der Linden, (2000). Age-related differences in supervisory attentional system functions. *Journal of Gerontology: Psychological Science, 55B*, 373-380.

Ball, K., Berch, D. B., Helmers, K. F., Jobe J. B., Leveck, M. D., Marsiske, M., Morris, J. N., Rebok, G. W., Smith, D. M., Tennstedt, S. L., Unverzagt, F.W., & Willis, S.L. (2002). Effects of cognitive training interventions with older adults: A randomized controlled trial. *Journal of the American Medical Association, 288*, 2271-2281.

Barnett, S.M., & Ceci S. J. (2002). When and where do we apply what we learn ? A taxonomy for far transfer. *Psychological bulletin, 128*, 612-637.

Bedard, A., Nichols, S., Barbosa, J. A., Schachar, R., Logan, G. D., & Tannock, R. (2002). The development of selective inhibitory control across the life span. *Developmental Neuropsychology, 21*, 93-111.

Belleville, S., Rouleau, N., & Van der Linden (2006). Use of the Hayling task to measure inhibition of prepotent responses in normal aging and Alzheimer's disease. *Brain and Cognition, 62*, 113-119.

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2005). Training effects on dual-task performance: Are there age-related differences in plasticity of attentional control ? *Psychology and Aging, 20*, 695-709.

Bherer, L., Kramer, A.F., Peterson, M.S., Colcombe, S., Erickson, K., & Becic, E. (2008). Transfer effects in task-set cost and dual-task cost after dual-task training in older and younger adults: Further evidence for cognitive plasticity in attentional control in late adulthood. *Experimental Aging Research, 34*, 188-219.

Bielak, A. A., Mansueti, L., Strauss, E., & Dixon, R. A. (2006). Performance on the Hayling and Brixton tests in older adults: Norms and correlates. *Archives of Clinical Neuropsychology, 21*, 141-149.

Bohnen, N., Jolles, J., & Twijnstra, A. (1992). Modification of the Stroop Color Word Test improves differentiation between patients with mild head injury and matched controls. *The Clinical Neuropsychologist, 6*, 178-184.

Boyle, P. A., Paul, R. H., Moser, D. J., & Cohen, R. A. (2004). Executive impairments predict functional declines in vascular dementia. *The clinical Neuropsychologist, 18* (1), 75-82.

Brenes, G. A. (2003). Cognitive training may improve targeted cognitive functions in older adults. *Evidence-Based Mental Health, 6*, 54.

Bugos, J. A., Perlstein, W. M., McCrae, C.S., Brophy, T.S., & Bedenbaugh, P.H. (2007). Individualized piano instruction enhances executive functioning and working memory in older adults. *Aging & Mental Health, 11*, 464-471.

Burgess, P. W., & Shallice, T. (1996). Response suppression, initiation and strategy use following frontal lobe lesions. *Neuropsychologi*a, *34*, 263-273.

Cattell, R. B. (1963). Theory of fluid and crystallized intelligence: A critical experiment. *Journal of Educational Psychology, 54*, 1-22.

Chatelois, J., Van Der Linden, M., Rouleau, N., De Courcy, R., Crépeau, F., & Malenfant, A. (1996). Stroop Flexibilité-4 couleurs (unpublished data).

Collette, F., Schmidt, C., Scherrer, C., Adam, S., & Salmon, E. (2007). Specificity of inhibitory deficit in normal aging and Alzheimer's disease, *Neurobiology of Aging,* (in press, corrected proof).

Collette, F., Van der Linder, M., Delfiore, G., Degueldre, C., Luxen, A., & Salmon, E. (2001). The functional anatomy on inhibition processes investigated with the Hayling task. *Neuroimage, 14*, 258-267.

Dahlin, E., Nyberg, L., Bäckman, L., & Stigsdotter Neely, A. (2008). Plasticity of executive functioning in young and older adults: Immediate training gains, transfer and long-term maintenance. *Psychology and Aging, 23*, 720-730.

Davidson, D. J., Zacks, R. T., & Williams, C.C. (2003). Stroop interference, practice, and aging. *Aging Neuropsychology and Cognition, 10*, 85-98.

Dulaney, C.L., & Roger, W. A. (1994). Mechanisms underlying reduction in Stroop interference with practice for young and old adults. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*, 470-484.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975) Mini-Mental State: A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12*, 189-198.

Friendman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: a latent-variant analysis. *Journal of Experimental Psychology: General, 133*, 101-135.

Hasher, L., & Zacks, R. (1988). Working memory, comprehension, and aging: A review and new view. In G.H. Bower (Eds.). *The psychological of learning and motivation: Advances in research and theory* (Vol. 22, pp. 193-225). New York: Academic Press.

Healey, M.K., Campbell, K.L., & Hasher, L. (2008). Cognitive aging and increased distractibility: Costs and potential benefits. *Progress in brain research, 169*, 353-363.

Jefferson, A. L., Paul, R.H., Ozonoff, A., & Cohen, R. A. (2006). Evaluation elements of executive functioning as predictors of instrumental activities of daily living (IADLs). *Archives of clinical neuropsychology, 21*, 311-320.

Keys, B. A. (2002). Age-related deficits in inhibition: Exploring the role of endogenous control. *Dissertation Abstracts International: Section B: The Sciences & Engineering, 63*(10-B).

Kok, A. (1999). Varieties of inhibition : manifestations in cognition, event-related potentials and aging. *Acta Psychologica, 101*, 129-158.

Kramer, A. F., Humphrey, D, G., Larish, J.F., Logan, G.D., & Strayer, D. L. (1994). Aging and inhibition: Beyong a unitary view of inhibitory processing in attention. *Psychology and Aging, 9*, 491-512.

Kramer, A.F., Larish, J. F., & Strayer, D.L. (1995). Training for attentional control in dual task settings: A comparison of young and old adults. *Journal of Experimental Psychology: Applied, 1*, 50-76.

Kramer, A. F., Larish, J. L., Weber, T. A., & Bardell, L. (1999). Training for executive control: Task coordination strategies and aging. In Gopher and Koriat (Eds.) *Attention and Performance* XVII (pp. 617-652). Cambridge, MA: MIT Press.

Kramer, A. F., & Madden, D. J. (2008). Attention. In F. I. M. Craik and T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp.189-249). New York: Psychology Press.

Lezak, M. D., Howieson, D. B., & Loring, D. W. (2004). *Neuropsychological assessment (4th Edition)*. New York: Oxford University Press.

Logan, G. D. (1994). On the ability to inhibit thought and action: A users'guide to the stop signal paradigm. In D.D. Carr & T.H. Carr (Eds.), *Inhibitory processes in attention, memory, and language* (pp. 189-239). San Diego: Academic.

Lustig, C., Hasher, L., & Zacks, R. (2007). Inhibitory deficit theory: Recent developments in a «new view». In D.S. Gorfein and C.M. Macleod (Ed.), *The place of inhibition in cognition* (pp. 145-162), Washington: American Psychological Association.

May, C.P., & Hasher, L. (1998). Synchrony effects in inhibitory control over thought and action. *Journal of Experimental Psychology : Human Perception and Performance, 24*, 363-379.

Maylor, E., Schlaghecken, F., & Watson, D. G. (2005). Aging and inhibitory processes in memory, attentional, and motor tasks. In R.W. Engle, G. Sedek, U. V. Hecker, & D. N. McIntosh (Eds.), *Cognition limitations in aging and psychopathology* (pp. 313-345). Cambridge, Cambridge University Press.

McCrae, C. S., & Abrams, R. A. (2001). Age-Related Differences in Object and Location-Based Inhibition of Return of Attention. *Psychology and Aging, 16*, 437-449.

McDowd, J. M., & Shaw, R. J. (2000). Attention and aging : A functional perspective. In F. I. M. Craik and T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp.221-292). Hillsdale, NJ: Lawrence Erlbaum Associates.

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: Views from cognitive and personality psychology and a working inhibition taxonomy, *Psychological Bulletin, 126*, 200-246.

Rush, B. K., Barch, D. M., & Braver, T. S. (2006). Accounting for cognitive aging : Context processing, inhibition or processing speed. *Aging, Neuropsychology, and Cognition, 13*, 588-610.

Salomon, G., & Perkins, D. N. (1989). Rocky roads to transfer : Rethinking mechanisms of a neglected phenomenon. *Educational Psychologist, 24*, 113-142.

Schmidt, R. A., & Bjork, R. A. (1992). New conceptualizations of practice: Common principles in three paradigms suggest new concepts for training. *Psychological Science, 3*, 207-217.

SPSS (2003). *Advanced Statistics 12.0.* Chicago, IL: SPSS Inc.

Sweeney, J.A., Rosano, C. , Berman, R. A., & Luna, B. (2001). Inhibitory control of attention declines more than working memory during normal aging. *Neurobiology of aging, 22*, 39-47.

Thorndike, E. L., & Woodworth, R. S. (1901). The influence of improvement in one mental function upon the efficiency of other functions. *Psychological Review, 8*, 247-261.

Van der Schoot, M., Licht, R., Horsley, T. M., & Sergeant, J. A. (2005). Effects of stop signal modality, stop signal intensity and tracking method on inhibitory performance as determined by use of the stop signal paradigm. *Scandinavian journal of psychology, 46*, 331-341.

Wechsler, D. (1997). Wechsler Adult Intelligence Scale-III. San Antonio: The Psychological Corporation.

Williams, B.R., Ponesse, J.S., Schachar, R. S., Logan, G. D., & Tannock, R. (1999). Development of inhibitory control across the life span. *Developmental Psychology, 35*, 205-213.

Willis, S. L. (2001). Methodological Issues in Behavioral Intervention Research with the Elderly. In J.E. Birren & K.W. Schaie (Eds.). *Handbook of the psychology of Aging*. Fifth Edition (pp. 78-102). New York: Academic Press.

Yesavage, J. A., Brink, T.L, Rose, T. L., Lum, O., Huang, V., Adey, M., & Leirer, V. O. (1983). Development and validation of a geriatric depression screening scale: A preliminary report. *Journal of Psychiatric Research, 17*, 37-49.

Zelinski, E. What does training train, and other questions: yet another overview of training. Paper presented at the Cognitive Aging Conference, Atlanta, GA, April, 2008.

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Table 1

Means Scores for Participants Characteristics and General Cognitive Abilities

(SD in parenthesis)

	Older		Younger	
	Training	Control	Training	Control
Age	74.07	74.14	21.58	21.58
	(4.92)	(5.76)	(2.81)	(2.31)
School Education	13.36	13.64	14.17	14.58
	(2.65)	(2.31)	(1.34)	(1.98)
Mini Mental State Examination	29.21	29.07		
	(0.89)	(0.99)		
Geriatric Depression Scale	3.29	2.36		
(Raw score on 30 points)	(2.79)	(2.02)		
Digit Symbol-Coding***	53.71	54.21	92.08	85.67
(Raw score on 133 points)	(10.43)	(12.14)	(11.73)	(12.91)
Matrix Reasoning***	14.57	12.29	22.17	22.00
(Raw score on 26 points)	(4.93)	(4.25)	(2.59)	(2.09)
Digit Span***	16.93	15.36	19.17	20.17
(Raw score on 30 points)	(3.20)	(3.30)	(2.13)	(3.95)
Similarities from WAIS-III***	23.71	22.00	27.67	27.58
(Raw score on 33 points)	(3.91)	(4.47)	(3.14)	(3.23)
Phonetic Fluency Test	50.86	43.64	53.92	51.92
(Total number of words)	(12.35)	(12.46)	(10.53)	(7.06)

Note. An Analyse of variance revealed some age-related differences in favour of younger.
*p < .05 ** p <.005 *** p < .00

Table 2

Mean results in the Auditory Stop-Signal Task in six training sessions (SD in parenthesis)

	Older training group						Younger training group					
Training Sessions	1	2	3	4	5	6	1	2	3	4	5	6
GoRT	667.85	668.24	672.20	641.21	656.91	662.62	418.31	406.16	411.76	399.53	410.97	418.86
	(147.99)	(169.25)	(184.16)	(178.64)	(198.21)	(199.72)	(99.81)	(93.75)	(108.12)	(75.13)	(122.20)	(121.88)
AgoRT	828.92	784.22	764.82	744.81	736.63	734.60	475.58	453.95	459.87	452.07	453.45	468.47
	(199.28)	(170.81)	(209.75)	(204.88)	(241.19)	(209.21)	(107.37)	(77.54)	(108.68)	(93.31)	(121.32)	(142.43)
SSRT	302.88	264.59	260.72	256.94	258.44	254.21	305.81	293.36	302.73	306.29	312.45	306.95
	(77.56)	(57.88)	(56.65)	(76.78)	(67.34)	(54.74)	(65.33)	(64.68)	(57.93)	(58.39)	(60.62)	(69.16)
ASSRT	463.95	380.57	353.34	360.55	338.15	326.18	363.08	341.16	350.84	358.81	354.94	356.57
	(107.01)	(58.84)	(69.13)	(68.02)	(80.91)	(60.66)	(53.27)	(78.57)	(68.80)	(60.32)	(50.16)	(56.48)
%SS	52.36	52.64	51.29	48.64	48.71	48.43	43.17	42.92	42.25	40.58	38.25	35.50
	(4.65)	(4.62)	(3.63)	(14.33)	(15.02)	(14.36)	(14.31)	(11.23)	(8.24)	(9.22)	(13.84)	(15.73)
%NSS	99.97	99.98	99.99	99.99	99.99	99.98	99.96	99.97	99.96	99.97	99.98	99.96
	(0.05)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.04)	(0.02)	(0.05)	(0.04)	(0.03)	(0.05)
%Go	98.21	98.29	98.93	98.36	98.14	98.71	96.50	96.42	96.58	96.92	94.17	95.08
	(1.58)	(1.90)	(1.33)	(1.82)	(1.99)	(1.82)	(2.81)	(3.18)	(3.09)	(2.47)	(6.35)	(5.52)

Note. SSRT = Stop-Signal reaction time (milliseconds); ASSRT= alternative Stop-Signal reaction time (milliseconds); GoRT = Go reaction time (milliseconds); AGoRT = Alternative Go reaction time (milliseconds); SSd = Stop-Signal delay (milliseconds); %SS = percentage of inhibition responses given the Stop-Signal; %NSS = percentage of trial completed given the non-stop signal; %Go = percentage of correct Go responses.

Table 3

Mean results in the Stop-Signal Tasks in pre-test and post-test sessions (SD in parenthesis)

	Older				Younger			
	Training		Control		Training		Control	
Auditory Stop-Signal task	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
GoRT	684.98 (154.82)	652.56 (207.36)	698.86 (118.86)	704.86 (152.60)	421.83 (53.97)	426.48 (140.44)	449.55 (64.94)	437.90 (65.19)
AgoRT	874.23 (199.76)	742.17 (239.39)	869.25 (242,72)	876.18 (232.64)	513.71 (89.10)	466.41 (137.48)	527.92 (78.56)	501.26 (71.33)
SSRT	348.34 (85.05)	250.11 (60.49)	353.47 (118.33)	327.53 (119.95)	324.84 (71.45)	315.94 (64.19)	312.05 (73.76)	314.75 (61.27)
ASSRT	537.59 (133.37)	339.71 (64.11)	523.85 (173.79)	498.85 (251.25)	416.72 (68.83)	355.87 (59.26)	390.42 (86.57)	378.11 (64.96)
%SS	53.93 (5.28)	49.21 (16.14)	50.79 (10.63)	52.14 (7.79)	40.83 (12.75)	34.33 (15.62)	44.50 (11.45)	44.25 (8.86)
%NSS	99.95 (0.05)	99.99 (0.02)	99.97 (0.05)	99.98 (0.04)	99.95 (0.05)	99.96 (0.05)	99.95 (0.07)	99.96 (0.06)
%Go	97.07 (2.73)	98.79 (1.85)	97.36 (2.5)	98.57 (1.02)	97.83 (1.85)	95.42 (3.18)	97.92 (1.98)	97.25 (2.63)
Visual Stop-Signal task	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
GoRT	707.01 (196.32)	658.50 (221.57)	738.20 (186.45)	740.23 (193.68)	420.81 (128.14)	413.27 (149.38)	451.36 (115.74)	430.11 (78.51)
AgoRT	815.53 (180.84)	737.70 (233.38)	881.08 (204.39)	847.84 (185.25)	473.70 (129.98)	449.99 (151.33)	482.90 (108.85)	465.35 (81.14)
SSRT	302.68 (49.10)	293.25 (64.67)	321.10 (62.62)	283.51 (55.80)	279.14 (44.06)	294.97 (43.34)	277.98 (46.14)	269.12 (52.67)
ASSRT	411.20 (76.25)	372.45 (99.96)	463.98 (90.73)	391.13 (61.43)	332.03 (43.86)	331.70 (38.31)	309.52 (48.84)	304.35 (45.32)
%SS	51.00 (5.83)	47.21 (13.89)	54.07 (5.55)	52.50 (4.55)	44.17 (11.50)	40.58 (12.80)	49.00 (2.34)	46.25 (8.31)
%NSS	99.99 (0.02)	99.98 (0.03)	99.98 (0.03)	99.98 (0.03)	99.98 (0.03)	99.97 (0,03)	99.99 (0.01)	99.99 (0.01)
%Go	97.93 (1.82)	98.93 (1.69)	97.64 (1.15)	98.86 (1.10)	98.67 (1.56)	97.75 (3.36)	98.25 (1.71)	98.25 (3.65)

Note. SSRT = Stop-Signal reaction time (milliseconds); ASSRT= alternative Stop-Signal reaction time (milliseconds); GoRT = Go reaction time (milliseconds); AGoRT = Alternative Go reaction time (milliseconds); SSd = Stop-Signal delay (milliseconds); %SS = percentage of inhibition responses given the Stop-Signal; %NSS = percentage of trial completed given the non-stop signal; %Go = percentage

Table 4

Mean Scores in Neuropsychological Tests in Pre-test and Post-test Sessions (SD in parenthesis)

	Older				Younger			
	Training		Control		Training		Control	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Hayling Test / automatic condition**	16.43	15.36	17.21	15.71	15.00	15.00	15.00	15.00
(Time in s)	(2.03)	(0.84)	(2.70)	(1.20)	(0.00)	(0.00)	(0.00)	(0.00)
Hayling Test / inhibition condition***	92.43	65.43	71.64	55.93	36.08	29.25	33.00	26.83
(Time in s)	(58.48)	(43.47)	(41.19)	(32.72)	(15.52)	(15.97)	(12.54)	(9.75)
Hayling Test / inhibition condition***	5.29	2.21	6.86	5.57	1.83	1.58	2.08	1.75
(Errors)	(2.70)	(1.85)	(2.11)	(2..95)	(1.34)	(0.90)	(1.44)	(1.66)
Stroop/word reading*	45.29	47.79	46.62	47.15	40.25	38.25	40.92	40.00
(Time in s)	(12.09)	(13.34)	(6.36)	(5.54)	(5.61)	(3.11)	(3.00)	(3.52)
Stroop/word reading	0.07	0.00	0.23	0.08	0.00	0.08	0.08	0.00
(Corrected errors)	(0.27)	(0.00)	(0.44)	(0.28)	(0.00)	(0.29)	(0.29)	(0.00)
Stroop/colors naming***	68.86	63.50	66.23	67.62	54.75	52.08	56.67	53.75
(Time in s)	(15.87)	(10.21)	(8.88)	(9.27)	(3.96)	(3.94)	(9.48)	(7.65)
Stroop/colors naming**	0.86	0.14	0.77	0.77	0.08	0.00	0.17	0.50
(Corrected errors)	(0.86)	(0.36)	(0.83)	(1.01)	(0.29)	(0.00)	(0.58)	(1.00)
Stroop/color-word interference***	118.93	105.57	138.31	121.92	84.00	76.25	89.33	79.67
(Time in s)	(19.57)	(17.66)	(30.08)	(24.77)	(11.69)	(9.31)	(16.07)	(14.72)
Stroop/color-word interference	2.21	1.93	2.69	2.08	1.58	1.42	1.83	1.75
(Corrected errors)	(2.42)	(1.54)	(2.36)	(1.44)	(1.56)	(1.31)	(1.75)	(2.14)
Stroop/color-word flexibility***	135.14	114.07	145.00	138.54	97.33	90.17	103.67	90.83
(Time in s)	(21.90)	(17.44)	(20.72)	(25.63)	(13.29)	(11.95)	(18.83)	(16.06)
Stroop/color-word flexibility	2.79	1.43	2.23	2.85	1.42	0.92	1.17	1.75
(corrected color errors)	(2.55)	(1.79)	(3.06)	(2.73)	(1.31)	(0.90)	(1.19)	(1.55)

Note. An Analyse of variance at baseline revealed some age-related differences in favour of younger. *$p < .05$ ** $p < .005$ *** $p < .001$

Figure Captions

Figure 1. An illustration of the auditory Stop-Signal task.

Figure 2. Mean Stop-Signal Reaction Time (ms) in pre-test and post-test sessions in both the control and the training groups of older adults and younger adults.

Figure 3. Mean alternative Stop-Signal Reaction Time (ms) in pre-test and post-test sessions in both the control and the training groups of older and younger adults.

Figure 4. Percentage of change after training ((Pre-test + 1) – (Post-test + 1)/(Pre-test + 1)*100) in the Hayling Test in both the control and the training groups of older adults.

Figure 5. (A) Percentage of change after training ((pre-test – post-test/pre-test)*100) in time to complete the Flexibility condition of the Stroop Test and (B) Percentage of change in corrected errors during the Stroop Flexibility condition ((pre-test + 1) – (post-test + 1)/(pre-test + 1)*100) in both the control and the training groups of older adults.

Figure 1

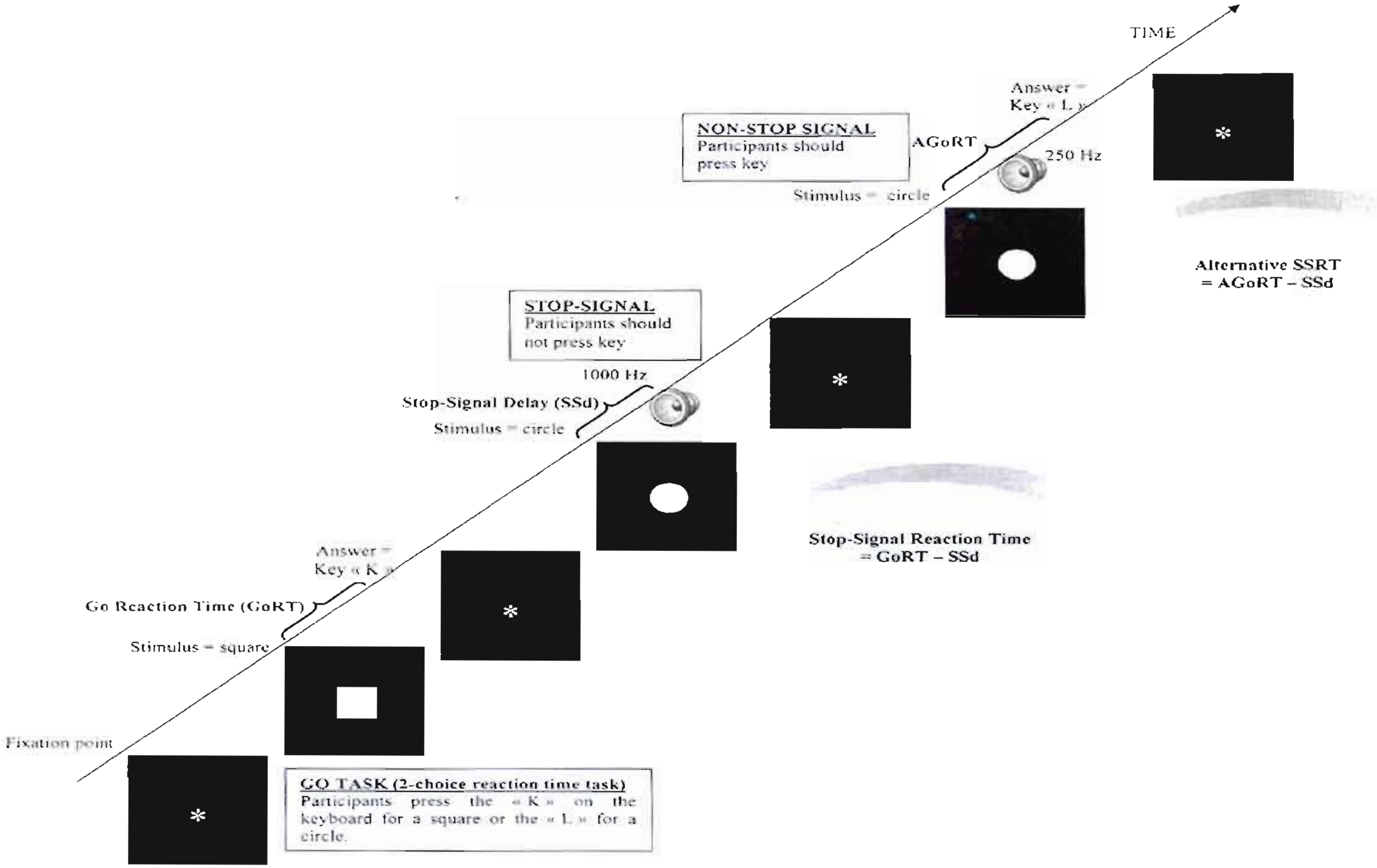

TIME
Answer =
Key « L »
NON-STOP SIGNAL
Participants should
press key
AGoRT
250 Hz
Stimulus = circle
Alternative SSRT
= AGoRT – SSd
STOP-SIGNAL
Participants should
not press key
1000 Hz
Stop-Signal Delay (SSd)
Stimulus = circle
Stop-Signal Reaction Time
= GoRT – SSd
Answer =
Key « K »
Go Reaction Time (GoRT)
Stimulus = square
Fixation point
GO TASK (2-choice reaction time task)
Participants press the « K » on the keyboard for a square or the « L » for a circle.

Figure 2

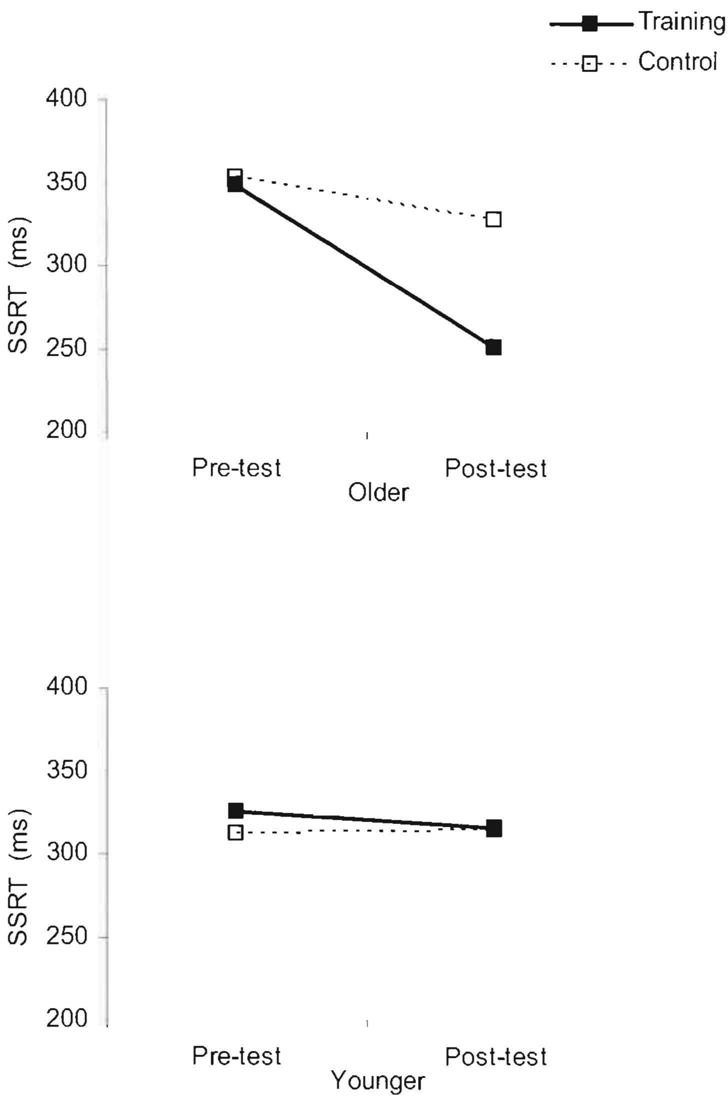

Training
Control
400
350
300
250
200
SSRT (ms)
Pre-test
Post-test
Older
400
350
300
250
200
SSRT (ms)
Pre-test
Post-test
Younger

Figure 3

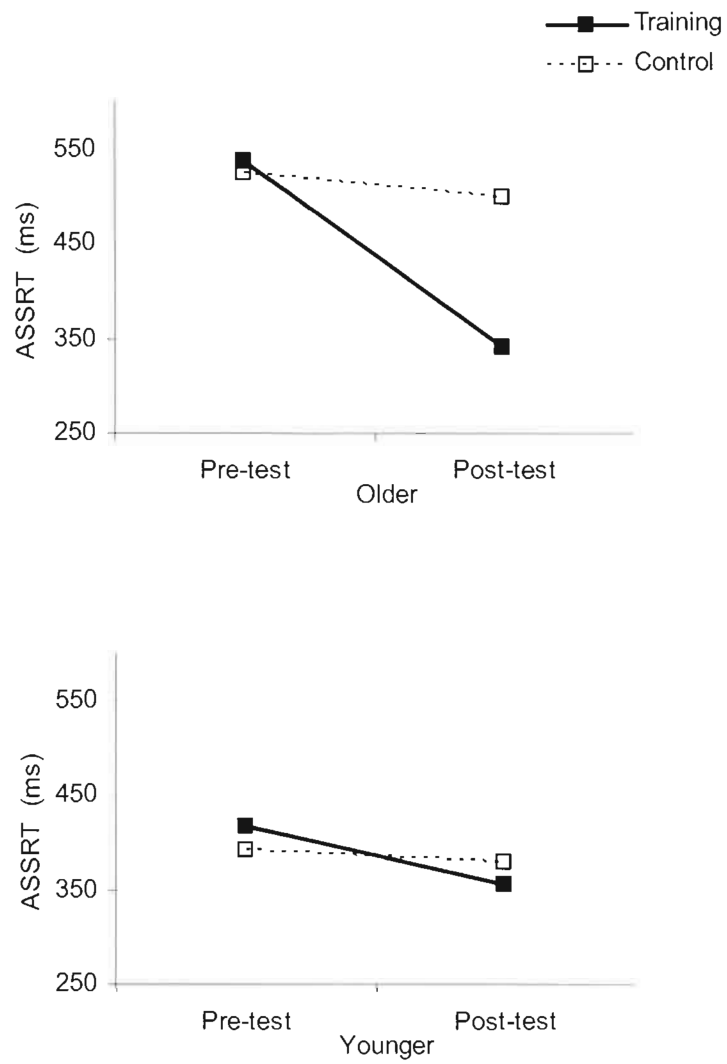

Training
Control
550
450
350
250
ASSRT (ms)
Pre-test
Post-test
Older
550
450
350
250
ASSRT (ms)
Pre-test
Post-test
Younger

Figure 4

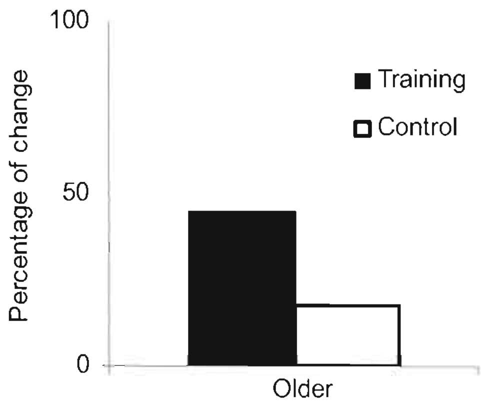
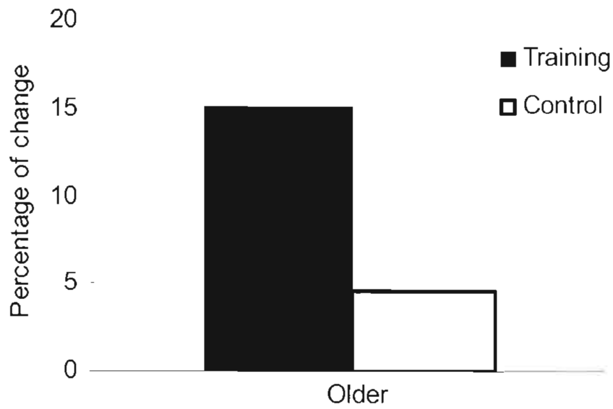
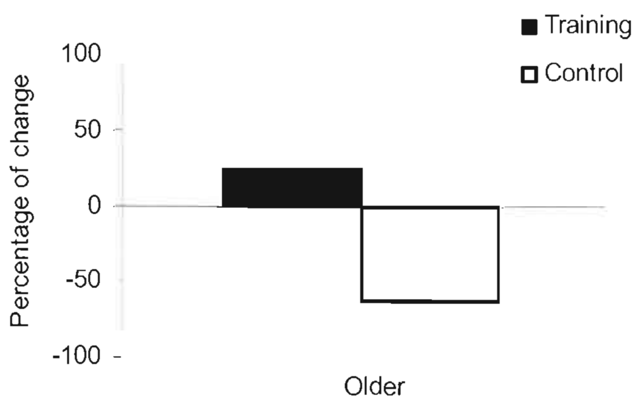


Figure 5

(A)


20
15
10
5
0
Percentage of change
Training
Control
Older

(B)


100
50
0
-50
-100
Percentage of change
Training
Control
Older

CHAPITRE IV

DISCUSSION GÉNÉRALE

DISCUSSION GÉNÉRALE

Des études ont récemment démontré que l'efficience des mécanismes de contrôle de l'attention, tels que ceux requis dans la coordination de tâches multiples, peut être améliorée suite à des entraînements cognitifs informatisés (Kramer et al., 1995, 1999; Bherer et al., 2005, 2008). Cependant, peu d'études ont montré des preuves de transfert ou de généralisation des acquis à des tâches cliniques. Les résultats de nos deux recherches indépendantes ont montré des effets de transfert spécifiques à des tests neuropsychologiques cliniques suite à un entraînement cognitif de l'attention. L'entraînement de l'attention divisée a amélioré les habiletés d'alternance (switching) telles qu'évaluées par la condition flexibilité du Stroop et la partie B du Traçage de pistes, alors que l'entraînement de l'inhibition a montré des effets positifs au test de Stroop et au test de Hayling. Ces résultats suggèrent que l'entraînement cognitif peut améliorer les fonctions attentionnelles des personnes âgées, telles que mesurées à l'aide de tests neuropsychologiques cliniques.

4.1. Vieillissement et entraînement de l'attention divisée

L'objectif de la première étude était de vérifier si un entraînement en double tâche, similaire à celui utilisé par Bherer et al. (2005, 2008), permet d'améliorer significativement la performance des aînés à des épreuves neuropsychologiques fréquemment utilisées en clinique pour évaluer les fonctions attentionnelles. D'une part, les résultats ont montré une amélioration de la performance à la tâche d'entraînement. En effet, la vitesse et l'exactitude des réponses des aînés entraînés se sont significativement améliorées comparativement aux aînés du groupe contrôle. Ces résultats sont compatibles avec ceux obtenus dans d'autres études utilisant une procédure similaire (Bherer et al, 2005; Kramer, Larish, Weber, & Bardell, 1999). D'autre part, les habiletés de partage attentionnel acquises pendant l'entraînement semblent montrer une généralisation de l'apprentissage. Une amélioration de la performance aux tests neuropsychologiques impliquant de la vitesse psychomotrice (Substitution) et de la flexibilité attentionnelle (Stroop Flexibilité et Traçage de piste B) est constatée. Néanmoins, le transfert de l'apprentissage acquis durant l'entraînement semble spécifique aux habiletés ciblées par l'entraînement puisque les aînés entraînés n'ont pas obtenu des résultats supérieurs aux aînés contrôles dans les épreuves de recherche sélective visuelle (Recherche de symboles) et de mémoire de travail (Séquences lettres-chiffres).

Les trois types d'essais (simple-pur, simple-mixte et double-mixte) inhérents à notre entraînement en double tâche ont permis d'établir le coût situationnel (task-set cost) et le coût de la coordination (dual-task cost). Le coût situationnel (temps de réaction aux essais simple-mixtes – temps de réaction aux essais simple-purs) provient de la diminution de la performance observée aux essais simples lorsqu'ils sont exécutés parmi un bloc d'essais mixtes, comparativement aux résultats obtenus lors des blocs purs. Le coût de la coordination (temps de réaction aux essais double-mixtes – temps de réaction aux essais simple-mixtes) est associé à une diminution de la performance aux essais double-mixtes comparativement à celle obtenue aux essais simple-mixtes lors des blocs mixtes. Le même calcul est également effectué en ce qui concerne l'exactitude des réponses.

Les résultats de notre étude ont montré une diminution du coût situationnel, tant au niveau du temps de réaction et de l'exactitude des réponses. Ce coût situationnel refléterait la capacité à maintenir les diverses associations entre les stimuli et les réponses des deux tâches en mémoire de travail. Améliorer le coût situationnel devrait réduire les ressources requises pour accomplir la double tâche et ainsi diminuer l'interférence. Comme mentionné précédemment, les effets de l'entraînement n'ont pas amélioré la performance à la tâche de mémoire de travail (Séquences lettres-chiffres). Une amélioration a toutefois été observée en ce qui concerne la partie B du Traçage de pistes qui est plus spécifiquement associée à la flexibilité cognitive, bien que l'épreuve sollicite également la mémoire de travail (ex. maintenir en mémoire de travail l'ordre alphabétique et l'ordre numérique afin d'alterner correctement entre les deux catégories). La mémoire de travail est généralement associée aux fonctions exécutives qui seraient composées de plusieurs sous-composantes selon des modèles théoriques (Stuss, Shallice, Alexander, & Picton, 1995; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). Plusieurs recherches récentes ont évalué l'efficacité d'entraînements cognitifs visant à améliorer la performance en mémoire de travail et elles ont obtenu des effets d'entraînement et de transfert prometteurs (Buschkuehl & Jaeggi, 2008; Dahlin, Nyberg, Bäckman, & Stigsdotter Neely, 2008; Dahlin, Stigsdotter, Larsson, Bäckman, & Nyberg, 2008; Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Li et al., 2008; Smith et al., 2009). Soulignons que dans notre entraînement informatisé, une inscription au bas de l'écran permettait au participant de toujours savoir à quelles touches les divers stimuli étaient associés; ce qui devait ainsi diminuer la charge en mémoire de travail.

Concernant le coût de coordination (dual-task cost), les résultats de notre étude ont montré que ce coût attentionnel a diminué suite à l'entraînement, en ce qui a trait à l'exactitude des réponses. L'amélioration serait liée à l'acquisition d'une meilleure coordination ou alternance entre les tâches, ce qui a sans doute favorisé le transfert des acquis aux tâches neuropsychologiques sollicitant de la flexibilité cognitive. En effet, une amélioration de la performance est observée pour le groupe d'aînés entraînés à la condition permettant d'isoler le coût attentionnel lié à l'alternance entre deux tâches au Traçage de pistes (Tracé B – Tracé A / Tracé A), alors que l'augmentation de la vitesse d'exécution au Tracé A ne diffère pas entre les groupes entraîné et contrôle. Le groupe d'aînés entraînés s'améliore également à la condition flexibilité du Stroop (temps de réaction et erreurs) alors que ce n'est pas le cas pour certaines conditions du Stroop qui n'impliquent pas de capacités d'alternance (ex. conditions lecture et interférence). De plus, la rétroaction individualisée (feedback) inclue dans l'entraînement a sans doute permis aux participants d'ajuster leur performance en fonction des consignes de la tâche, tout en les poussant à atteindre des niveaux de difficulté plus élevés. Étant donné que l'autorégulation du contrôle exécutif semble diminuer avec l'âge (Dunlosky, Kubat-Silman, & Hertzog, 2003), la présence d'une rétroaction pendant une tâche pourrait donc aider les personnes âgées à mieux ajuster leur performance et favoriser le développement de stratégies plus efficientes dans la coordination des tâches concurrentes. Le contrôle attentionnel en serait ainsi optimisé. Cette rétroaction individualisée, qui pousse les participants à augmenter leur vitesse de performance, semble avoir favorisé une augmentation de la vitesse psychomotrice puisque les effets de l'entraînement se sont généralisés à une tâche de coordination visuo-motrice typiquement associée à la vitesse psychomotrice (Substitution). Dans cette dernière épreuve, la clé de référence (symboles associés à des chiffres) est toujours visible dans la partie supérieure de la feuille. Néanmoins, si le participant apprend rapidement et maintient facilement les diverses associations en mémoire de travail, la vitesse de performance devrait s'accentuer. Ainsi, certaines tâches neuropsychologiques sollicitent plus d'un domaine cognitif et ne comportent pas de sous-conditions isolant certains processus, ce qui ne permet pas de déterminer précisément quels sont les habiletés ou mécanismes qui se sont améliorés suite à l'entraînement.

Dans une étude récente, Erickson et al. (2007) ont vérifié la nature des changements corticaux relatifs à un entraînement en double tâche dont la procédure s'avère fort similaire à celle utilisée dans la présente étude. Les résultats indiquent que l'amélioration de la performance en double tâche est corrélée avec une augmentation de l'asymétrie hémisphérique et une réduction des différences liées à l'âge au niveau des activations préfrontales ventrales et dorsales. Une diminution de l'activité cérébrale au niveau de la région dorsolatérale du cortex préfrontal est, entre autres, notée chez les personnes âgées suite à l'entraînement cognitif. Cette observation est interprétée comme résultant d'une utilisation plus efficiente de cette région cérébrale ou des ressources cognitives requises en ce qui a trait au contrôle cognitif et à la coordination en double tâche. Les tâches neuropsychologiques ayant montré des effets de transfert dans notre étude (Substitution, Stroop Flexibilité et Traçage de piste B) semblent également solliciter la région dorsolatérale du cortex préfrontal (MacDonald et al., 2000; Stuss et al., 2001; Moll et al., 2002; Zakzanis et al., 2005; Nakahachi, 2008), ce qui appuie ainsi les hypothèses d'Erickson et al. (2007) sur les effets bénéfiques de l'entraînement quant à une meilleure utilisation de cette région préfrontale. Ces résultats démontrent l'importance de ces études sur l'entraînement de l'attention divisée puisqu'elles révèlent le potentiel de plasticité cognitive qui semble demeurer avec l'avancée en âge.

4.2. Vieillissement et entraînement de l'inhibition

La deuxième étude avait pour objectif principal d'évaluer l'efficacité d'un protocole d'entraînement cognitif ciblant un autre aspect du contrôle exécutif particulièrement sensible à l'âge, soit la capacité d'inhibition requise dans des tâches où l'on doit stopper une réponse en cours d'exécution (paradigme de la tâche du signal d'arrêt). Une tâche de signal d'arrêt auditif sélectif a été utilisée en guise d'entraînement. Cette tâche d'inhibition sélective est plus exigeante cognitivement selon Bedard et al. (2002) mais semble plus écologique que la tâche du signal d'arrêt classique qui demande aux participants de cesser toute action dès qu'un signal d'arrêt survient. En effet, dans la vie de tous les jours, les situations qui requièrent un arrêt de l'action planifiée, suite à un signal quelconque, impliquent rarement un arrêt complet pour tous les stimuli. La conduite automobile en est un bon exemple car un « signal d'arrêt » peut survenir alors que l'individu se trouve dans une situation d'attention divisée où stopper tout mouvement pourrait s'avérer inapproprié.

Les résultats de l'étude ont montré qu'il est possible d'améliorer le contrôle de l'inhibition des aînés suite à un entraînement cognitif. En effet, une diminution du temps de réaction au signal d'arrêt est observée pour le groupe entraîné suite à l'entraînement comparativement au groupe contrôle. L'apprentissage acquis durant l'entraînement s'est également généralisé à des tâches neuropsychologiques impliquant les habiletés d'inhibition. Les résultats au test de Hayling semblent démontrer que les aînés entraînés commettent moins d'erreurs et ont donc plus de facilité à inhiber volontairement une réponse verbale automatique. Une amélioration de la performance est également observée au Stroop Flexibilité (vitesse et nombre d'erreurs). Ces améliorations ne semblent pas liées uniquement à l'augmentation de la vitesse ou à la familiarisation avec les tâches puisque la performance ne diffère pas entre les groupes entraîné et contrôle aux conditions de base du test de Stroop (ex : condition lecture) et du test de Hayling (condition automatique). En se référant à la théorie du déficit d'inhibition (Hasher, & Zacks, 1988; Lustig, Hasher, & Zacks, 2007) qui propose trois fonctions d'inhibition (accès, effacement et restriction), l'entraînement semble avoir amélioré la fonction « restriction » dont le rôle est de restreindre ou supprimer une réponse puissante ou automatique devenue inappropriée. De plus, le paradigme du signal d'arrêt sélectif semble partager des similitudes avec la condition flexibilité du Stroop puisque dans les deux tâches, un signal indique si la réponse prépondérante doit être inhibée ou non. Selon Kramer et al. (1994), la tâche du signal d'arrêt classique possède des composantes relatives à l'attention divisée puisque le participant doit surveiller l'apparition d'un signal tout en accomplissant la tâche principale. Rappelons que dans notre première étude, l'effet d'entraînement en double tâche a également montré une amélioration de la performance à la condition flexibilité du Stroop (vitesse et erreurs). Ainsi, si la tâche du signal d'arrêt sollicite également les fonctions d'attention divisée, il n'est pas surprenant qu'un effet de transfert soit à nouveau observé au Stroop Flexibilité qui sollicite à la fois des habiletés d'alternance et d'inhibition.

L'amélioration de la performance à ces tâches neuropsychologiques fréquemment utilisées en clinique semble montrer le potentiel prometteur des entraînements cognitifs. A notre connaissance, les seules études qui ont tenté d'améliorer les capacités d'inhibition chez les aînés concernent la pratique au Stroop (Davidson, Zacks, & Williams, 2003; Dulaney & Rogers, 1994). Ainsi, le développement de programmes d'entraînement cognitif efficaces ciblant l'inhibition semble important, d'autant plus que cette fonction semble particulièrement affectée par le vieillissement et reliée à l'intégrité du fonctionnement quotidien (Hasher & Zacks, 1988; Lustig, Hasher, & Zacks, 2007; Boyle, Paul, Moser, & Cohen, 2004; Jefferson, Paul, Oxonoff, & Cohen, 2006).

4.3. Efficacité des entraînements cognitifs et perspectives futures

Les résultats de la majorité des études d'entraînement cognitif tendent à démontrer que les fonctions cognitives qui ne sont pas sollicitées pendant l'entraînement ont peu de chance d'être améliorées. En effet, l'apprentissage acquis semble spécifique aux habiletés ciblées par l'entraînement, ce qui limite la généralisation au fonctionnement quotidien selon Green et Bavelier (2008). Dans une revue de la documentation, ces derniers auteurs ont récemment identifié certaines caractéristiques des programmes d'intervention qui augmentent les possibilités d'apprentissage. Ils mentionnent, entre autres, que les paradigmes d'entraînement amenant un apprentissage plus général sont typiquement plus complexes que les manipulations en laboratoire et plus semblables aux expériences de la vie quotidienne, tels que l'entraînement aux jeux vidéo, l'entraînement musical et l'entraînement athlétique. Par exemple, dans l'objectif d'améliorer les fonctions exécutives d'un groupe d'aînés, Basak, Boot, Voss, et Kramer (2008) ont soumis les participants à un entraînement d'une durée de 23.5 heures à l'aide d'un jeu vidéo complexe stratégique en temps réel (*Rise of Nations : Gold Edition*) procurant une rétroaction individualisée (feedback) et de fréquents changements de priorité à privilégier. La performance du groupe entraîné s'est améliorée significativement, par rapport au groupe contrôle, aux mesures liées au jeu vidéo mais également à des tâches de transfert mesurant la mémoire de travail, les habiletés d'alternance (switching), la mémoire visuelle à court-terme et le raisonnement.

Bugos, Perlstein, McCrae, Brophy, et Bedenbaugh (2007) ont également vérifié l'efficacité d'une intervention multimodale à l'aide d'un programme d'apprentissage individuel au piano auprès d'aînés. La performance à des tests neuropsychologiques (Substitution et Traçage de pistes A et B) s'est significativement améliorée pour le groupe entraîné comparativement au groupe contrôle. Ces derniers tests sont typiquement associés à des mesures de vitesse psychomotrice, d'exploration visuelle et de flexibilité cognitive (Lezak, Howieson, & Loring, 2004). L'entraînement au piano n'a cependant pas amélioré la performance à plusieurs sous-tests du WAIS-III, soit aux tests d'Empan de chiffres, de Dessins avec blocs et de Séquences lettres-chiffres. Ainsi, l'utilisation d'un programme multimodal n'est pas garant d'une généralisation à de multiples domaines cognitifs, du moins avec les personnes âgées. De plus, ce type de procédure d'apprentissage plus général ne permet pas de distinguer les mécanismes et facteurs déterminant l'efficacité des entraînements cognitifs, bien qu'il semble parfois favoriser le transfert de l'apprentissage selon Green et Bavelier (2008). Certains soutiennent que la variabilité de l'expérience d'apprentissage peut nuire à la phase d'acquisition mais assurait une plus grande capacité de transfert à de nouvelles tâches (Ahissar & Hochstein, 2004; Schmidt & Bjork, 1992).

Plusieurs auteurs examinent actuellement les caractéristiques des programmes d'intervention qui augmentent les possibilités d'apprentissage. Le but étant de créer des programmes d'intervention favorisant l'augmentation de la qualité de vie au niveau du quotidien. Green et Bavelier (2008) soutiennent que les tâches d'entraînement sont souvent ennuyantes et déplaisantes, ce qui doit nuire à l'adhésion au programme. La présence d'une rétroaction (apprentissage par renforcement), l'augmentation progressive du niveau de difficulté de l'entraînement, ainsi que favoriser un bon niveau d'éveil, de motivation et un sentiment d'autoefficacité sont d'autres facteurs importants à considérer. Des changements d'humeur, l'aspect social et le désir de plaire à l'expérimentateur pourraient aussi amener une amélioration temporaire de la performance. Cependant, ces derniers facteurs peuvent être contrôlés lorsque le groupe contrôle est également soumis à une intervention différente permettant ainsi la comparaison des résultats.

De plus en plus d'études s'intéressent actuellement aux répercussions des entraînements cognitifs sur la performance à d'autres tâches communément nommées « tâches de transfert ». L'objectif est de vérifier si les habiletés acquises lors de l'entraînement cognitif se généralisent à des situations différant de plus en plus de l'apprentissage initial (Willis, 2001). Les extrémités de ce continuum sont généralement représentées par deux catégories, soit un transfert proche (spécifique et proximal font partie des autres termes utilisés) et un transfert éloigné (ou aspécifique, distal). Les définitions du concept de transfert sont étroitement liées aux théories de l'apprentissage qui ont subi d'importantes modifications à travers le temps et peu de consensus existent quant aux aspects critiques du construit (Willis, 2001; Barnett & Ceci, 2002). La majorité des auteurs s'entendent toutefois sur l'une des conditions préalables au transfert selon laquelle une forme d'apprentissage doit d'abord survenir. Ainsi, selon Salomon et Perkins (1989), un transfert se produit lorsqu'un apprentissage acquis dans un contexte augmente la performance réalisée dans un contexte différent. En 1901, Thorndike et Woodworth prétendaient que si un transfert se produit, c'est parce que les deux situations possèdent des éléments communs et que seul un transfert à des situations fort similaires est probable. Par contre, l'étude du concept d'intelligence a amené des chercheurs comme Cattel (1963) a concevoir que l'être humain possède l'habileté d'abstraction lui permettant d'extraire des principes généraux de ses expériences d'apprentissage et de les appliquer ensuite à de nouvelles situations, ce qui assurait ainsi l'évolution et l'adaptation.

Selon plusieurs auteurs, le participant doit prendre conscience du principe ou de la stratégie apprise pendant l'entraînement pour permettre la généralisation par abstraction à des tâches de transfert éloigné (Barnett & Ceci, 2002; Geusgens, Winkens, Heugten, Jolles, & Heuvel, 2007; Salomon & Perkins, 1989; Willis, 2001). L'abstraction consciente permettrait un transfert éloigné car la règle, la stratégie ou le principe appris pourrait ensuite s'appliquer à des situations fort différentes de façon volontaire. Dans le même ordre d'idées, Geusgens et al. (2007) soutiennent que pour qu'un transfert à la vie quotidienne se produise, la personne entraînée devrait : 1- connaître ce qu'est le transfert et son fonctionnement, 2- prendre connaissance de son propre fonctionnement avant l'apprentissage de stratégies, 3- être capable de juger quand et où le transfert peut être appliqué, 4- apprendre des connaissances générales étant donné qu'elles sont plus facilement transférables que celles qui sont spécifiques, 5- pratiquer à travers des situations variées, et 6- être confronté à des situations de transfert pendant l'apprentissage. Ainsi, le protocole relatif à nos deux programmes d'entraînement ne correspond pas à ces derniers pré requis, ce qui peut être considéré comme une limite de l'étude bien que l'objectif n'était pas de vérifier l'impact de l'entraînement sur le fonctionnement quotidien mais plutôt d'améliorer les fonctions cognitives, telles que mesurées à l'aide de tests neuropsychologiques. Par ailleurs, il est aussi permis de croire qu'être conscient de l'apprentissage n'est pas toujours nécessaire pour assurer le transfert des habiletés cognitives acquises à de nouvelles situations (ex : développement cognitif des enfants). Il est possible que le rôle des facteurs associés au transfert varie, entre autres, selon la population visée, le type d'entraînement choisi et l'apprentissage ou l'habileté ciblée par la pratique.

Barnett et Ceci (2002) ont proposé une taxonomie dans laquelle le transfert peut être classifié sur un continuum allant de « proche » à « éloigné » selon les contextes physique, temporal, fonctionnel, social et modal. Selon ce modèle, le transfert obtenu dans nos deux études serait considéré comme « proche » sur la majorité de ces dimensions. En effet, l'entraînement et les tâches de transfert sont effectués dans la même salle (contexte physique), immédiatement et un mois après l'entraînement (contexte temporal), individuellement (contexte social) et ils sollicitent les mêmes habiletés cognitives (contexte fonctionnel). Par contre, des effets de transfert ont été obtenus avec des tâches neuropsychologiques dont la modalité des stimuli et des réponses différait parfois.

Bien que le transfert obtenu dans nos études semble correspondre à la catégorie « proche » de la taxonomie de Barnett et Ceci (2002), les procédures expérimentales des entraînements informatiques différaient largement des procédures associées aux tâches neuropsychologiques cliniques. Ces tâches neuropsychologiques standardisées sont des outils permettant aux cliniciens l'évaluation des fonctions cognitives et le diagnostic de déficits attentionnels. Ainsi, améliorer la performance à ces tests suite à un entraînement informatisé semble prometteur afin de connaître quelles sont les fonctions cognitives spécifiquement améliorées par l'entraînement. Nos résultats appuient ceux de Smith et al. (2009) ayant montré que leur programme d'entraînement cognitif, désigné pour améliorer le fonctionnement du système sensoriel central, a le potentiel d'améliorer les fonctions cognitives des personnes âgées. Ils ont entraîné des personnes âgées à l'aide d'exercices informatisés visant à améliorer la vitesse et l'exactitude des réponses du processus d'information auditive ou de l'organisation acoustique de la parole (ex : discrimination de syllabes confondantes, reconstruction de séquences d'instructions verbales et identification de détails dans une histoire présentée verbalement). L'impact de l'entraînement s'est généralisé à des tâche de mémoire et d'attention (*Battery for the Assessment of Neuropsychological Status*, *Rey Auditory Verbal Learning Test*, *Digit span backwards*, *letter-number sequencing* et questionnaire d'autoperception cognitive). Ces résultats semblent indiquer que le potentiel de plasticité cognitive demeure avec l'avancée en âge. Rappelons que Erickson et al. (2007) ont observé que l'amélioration de la performance en double tâche, suite à un entraînement cognitif similaire au nôtre, était corrélée avec une augmentation de l'asymétrie hémisphérique et une réduction des différences liées à l'âge au niveau des activations préfrontales ventrales et dorsales. Qui plus est, les études auprès des animaux et des humains semblent démontrer que la pratique intensive peut améliorer la performance des systèmes sensoriels dans le cortex cérébral et que les changements de plasticité cérébrale au niveau des réseaux de régions corticales pertinentes au sein du système nerveux central seraient reliés à cette amélioration (Buonomano & Merzenich, 1998; Gilbert, Sigman, & Crist, 2001; Mahncke, Bronstone, & Merzenich, 2006).

En somme, les résultats des deux études rapportées dans cette thèse indiquent qu'il est possible d'entraîner les habiletés de partage attentionnel et d'inhibition des aînés. De plus, l'apprentissage s'est généralisé à des tâches neuropsychologiques utilisées en clinique pour évaluer des difficultés attentionnelles. Améliorer les habiletés de partage attentionnel et d'inhibition des aînés s'avère important sachant qu'elles diminuent généralement avec l'avancée en âge alors qu'elles sont impliquées dans maintes activités quotidiennes, comme la conduite automobile et les paramètres de la marche et de l'équilibre (Levy, Pashler, &

Boer, 2006; Melzer, Benjuya, & Kaplanski, 2001; Rogers & Chaparro, 2004; Woollacoot & Shumway-Cook, 2002). Par exemple, en situation d'attention divisée, les personnes âgées seraient davantage à risque de chutes et d'accidents piétonniers au moment de traverser une rue, étant donné le déclin attentionnel observé au cours du vieillissement (Hauer, Pfisterer, Weber, Wezler, Kliegel, & Oster, 2003; Sparrow, Bradshaw, Lamoureux, & Tirosh, 2002). Qui plus est, plusieurs études démontrent que la performance obtenue à des tests neuropsychologiques, mesurant les fonctions exécutives, prédit significativement le statut fonctionnel observé au niveau des habiletés de la vie quotidienne (Grisby et al., 1998; Cahn-Weiner et al., 2000; Royal et al. 2000; Bell-McGinty, 2002; Boyle et al., 2004; Tomaszewski et al., 2009). Ainsi, il serait intéressant d'explorer les effets de ce type d'entraînement cognitif sur les habiletés de conduite automobile, les paramètres de la marche et de l'équilibre, ainsi que l'impact longitudinal sur le nombre d'accidents de la route, de chutes et de traumatismes crâniens pouvant en résulter. Le développement d'interventions efficaces visant à améliorer les fonctions cognitives des aînés apparaît vital sachant que la détérioration cognitive est associée à des risques de déclin fonctionnel, de placement en hébergement de soins de longue durée et de mortalité (Sands et al., 2002; Yaffe et al., 2002; Yaffe, Petersen, Lindquist, Kramer, & Miller, 2006). Maintenir ou améliorer l'efficience cognitive des aînés apparaît fondamental afin de favoriser leur autonomie et leur qualité de vie.

BIBLIOGRAPHIE

(Introduction générale et discussion générale)

Ahissar, M., & Hochstein, S. (2004). The reverse hierarchy theory of visual perceptual learning. *Trends in Cognitive Sciences, 8*, 457-464.

Andrés, P., Guerrini, C., Phillips, L. H., & Perfect, T. J. (2008). Differential effects of aging on executive and automatic inhibition. *Developmental Neuropsychology, 33*, 101-123.

Andrés, P., & Van der Linden, M. (2000). Age-related differences in supervisory attentional system functions. *Journal of Gerontology: Psychological Science, 55B*, 373-380.

Amieva, H., Phillips, L. &, Della Sala, S. (2003). Behavioral dysexecutive symptoms in normal aging. *Brain & Cognition, 53*, 129-132.

Ball, K., Berch, D. B., Helmers, K. F., Jobe J. B., Leveck, M. D., Marsiske, M., Morris, J. N., Rebok, G. W., Smith, D. M., Tennstedt, S. L., Unverzagt, F.W., & Willis, S.L. (2002). Effects of cognitive training interventions with older adults: A randomized controlled trial. *Journal of the American Medical Association, 288*, 2271-2281.

Barnett, S.M., & Ceci S. J. (2002). When and where do we apply what we learn ? A taxonomy for far transfer. *Psychological bulletin, 128*, 612-637.

Basak, C., Boot, W. R., Voss, M. W., & Kramer, A. F. (2008). Can training in a real-time strategy video game attenuate cognitive decline in older adults. *Psychology and aging, 23*, 765-777.

Bedard, A., Nichols, S., Barbosa, J. A., Schachar, R., Logan, G. D., & Tannock, R. (2002). The development of selective inhibitory control across the life span. *Developmental Neuropsychology, 21*, 93-111.

Bell-McGinty, S., Podell, K., Franzen, M., Baird, A., D., & Williams, M. J. (2002). Standard measures of executive function in predicting instrumental activities of daily living in older adults. *International Journal of Geriatric Psychiatry, 17*, 828-834.

Belleville, S., Rouleau, N., & Van der Linden (2006). Use of the Hayling task to measure inhibition of prepotent responses in normal aging and Alzheimer's disease. *Brain and Cognition, 62*, 113-119.

Bherer, L., Belleville, S., & Hudon, C. (2004). Le déclin des fonctions exécutives au cours du vieillissement normal, dans la maladie d'Alzheimer et dans la démence frontotemporale. *Psychologie et NeuroPsychiatrie du Vieillissement, 2*, 1-9.

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2005). Training Effects on Dual-Task Performance: Are There Age-Related Differences in Plasticity of Attentional Control ? *Psychology and Aging, 20*, 695-709.

Bherer, L., Kramer, A.F., Peterson, M.S., Colcombe, S., Erickson, K., & Becic, E. (2008). Transfer effects in task-set cost and dual-task cost after dual-task training in older and younger adults: Further evidence for cognitive plasticity in attentional control in late adulthood. *Experimental Aging Research, 34*, 188-219.

Bielak, A. A., Mansueti, L., Strauss, E., & Dixon, R. A. (2006). Performance on the Hayling and Brixton tests in older adults: Norms and correlates. *Archives of Clinical Neuropsychology, 21*, 141-149.

Boyle, P. A., Paul, R. H., Moser, D. J., & Cohen, R. A. (2004). Executive impairments predict functional declines in vascular dementia. *The clinical Neuropsychologist, 18* (1), 75-82.

Brenes, G. A. (2003). Cognitive training may improve targeted cognitive functions in older adults. *Evidence-Based Mental Health, 6*, 54.

Bugos, J. A., Perlstein, W. M., McCrae, C.S., Brophy, T.S., & Bedenbaugh, P.H. (2007). Individualized piano instruction enhances executive functioning and working memory in older adults. *Aging & Mental Health, 11*, 464-471.

Buonomano, D. V., & Merzenich, M. M. (1998). Cortical plasticity : From synapses to maps. *Annual Review of neuroscience, 21*, 149- 186.

Burgess, P. W., & Shallice, T. (1996). Response suppression, initiation and strategy use following frontal lobe lesions. *Neuropsychologia, 34*, 263-273.

Buschkuehl, M., & Jaeggi, S. M. (2008). Impact of working memory training on memory performance in old-old adults. *Psychology and Aging, 23*, 743-753.

Cahn-Weiner, D. A., Malloy, P. F., Boyle, P. A., Marran, M., & Salloway, S. (2000). Prediction of functional status from neuropsychological tests in community-dwelling elderly individuals. *The Clinical Neuropsychologist, 14*, 187-195.

Cattell, R. B. (1963). Theory of fluid and crystallized intelligence: A critical experiment. *Journal of Educational Psychology, 54*, 1-22.

Collette, F., Schmidt, C., Scherrer, C., Adam, S., & Salmon, E. (2007). Specificity of inhibitory deficit in normal aging and Alzheimer's disease, *Neurobiology of Aging,* (in press, corrected proof).

Collette, F., Van der Linder, M., Delfiore, G., Degueldre, C., Luxen, A., & Salmon, E. (2001). The functional anatomy on inhibition processes investigated with the Hayling task. *Neuroimage, 14*, 258-267.

Connelly. S. L., & Hasher, L. (1993). Aging and the inhibition of spatial location, Journal of experimental psychology. Journal of experimental psychology, *Human perception and performance, 19*, 1238-1250.

Dahlin, E., Nyberg, L., Bäckman, L., & Stigsdotter Neely, A. (2008). Plasticity of executive functioning in young and older adults: Immediate training gains, transfer, and long-term maintenance. *Psychology and Aging, 23*, 720-730.

Dahlin, E., Stigsdotter Neely, A., Larsson, A., Bäckman, L., & Nyberg, L. (2008). Transfer of learning after uptading training mediated by the striatum. *Science, 320*, 1510-1512.

Davidson, D. J., Zacks, R. T., & Williams, C.C. (2003). Stroop interference, practice, and aging. *Aging Neuropsychology and Cognition, 10*, 85-98.

Dulaney, C.L., & Rogers, W. A. (1994). Mechanisms underlying reduction in Stroop interference with practice for young and old adults. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*, 470-484.

Dunlosky, J., Kubat-Silman, A.K., & Hertzog, C. (2003). Training monitoring skills improves older adults'self-paced associative learning. *Psychology & Aging, 18*, 340-345.

Edwards, J. D., Wadley, V.G., Myers, R. S., Roenker, D. L., Cissell, G. M., & Ball, K. K. (2002). Transfer of a speed of processing intervention to near and far cognitive functions. *Gerontology, 48*, 329-340.

Edwards, J.D., Wadley, V.G., Vance, D.E., Wood, K., Roenker, D. L., & Ball. K.K. (2005). The impact of speed of processing training on cognitive and everyday performance. *Aging & Mental Health, 9*, 262-271.

Erickson, K. I., Colcombe, S. J., Wadhwa, R., Bherer, L., Peterson, M. S. , Scalf. P. E., Kim, J. S., Alvarado, M., & Kramer, A. F. (2007). Training-induced functional activation changes in dual-task processing: An fMRI study. *Cerebral Cortex, 17*, 192-204.

Erickson, K. I., Colcombe, S. J., Wadhwa, R., Bherer, L., Peterson, M. S. , Scalf. P. E., Kim, J. S., Alvarado, M., & Kramer, A. F. (2007). Training-induced plasticity in older adults: Effects of training on hemispheric asymmetry. *Neurobiology of Aging, 28*, 272-283.

Friendman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: a latent-variant analysis. *Journal of Experimental Psychology, 133*, 101-135.

Geusgens, C., Winkens, I., Van Heugten, C., Jolles, J., & Van den Heuvel , W. (2007). Occurrence and measurement of transfer in cognitive rehabilitation: a critical review. *Journal of rehabilitation medicine, 39*, 425-439.

Gilbert, C. D., Sigman, M., & Crist, R. E. (2001). The neural basis of perceptual learning. *Neuron, 31*, 681–697.

Green, C. S., & Bavelier (2008). Exercising your brain: A review of human brain plasticity and training-induced learning. *Psychology and Aging, 23*, 692-701.

Grigsby, J., Baxter, K. K., Shetterly, S., & Hamman, R. (1998). Executive cognitive abilities and functional status among community-dwelling older persons in the San Luis Valley Health and Aging Study. *Journal of American Geriatrics Society, 46*, 590-596.

Hartley, A. A. (1992). Attention. In F. I. M. Craik, & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 3-49). New Jersey : Lawrence Erlbaum Associates.

Hartley, A. A. (2001). Age differences in dual-task interference are localized to response generation processes. *Psychology and Aging, 16*, 47-54.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and new view. In G.H. Bower (Eds.). *The psychological of learning and motivation: Advances in research and theory* (Vol. 22, pp. 193-225). New York: Academic Press.

Hauer, K., Pfisterer, M., Weber, C., Wezler, N., Kliegel, M., & Oster, P. (2003). Cognitive impairment decreases postural control during dual tasks in geriatric patients with history of severe falls. *Journal of the American Geriatrics Society, 51*, 1638-1644.

Holtzer, R., Stern, Y., & Rakitin, B. C. (2005). Predicting age-related dual-task effects with individual differences on neuropsychological tests. *Neuropsychology, 19*, 18-27.

Hultsch, D. F., MacDonald, S., W., S., & Dixon, R. A. (2002). Variability in reaction time performance of younger and older adults. *Journal of Gerontology: Psychological Sciences, 57B*, P101-P115.

Jaeggi, S., Buschkuehl, M., Jonides, J., & Perrig, W. (2008). Improving fluid intelligence with training on working memory. *Proceedings of the National Academy of Sciences of the United States of America (PNAS), 19*, 6829-6833.

Jefferson, A. L., Paul, R.H., Ozonoff, A., & Cohen, R. A. (2006). Evaluation elements of executive functioning as predictors of instrumental activities of daily living (IADLs). *Archives of clinical neuropsychology, 21*, 311-320.

Jones, S., Nyberg, L., Sandblom, J., Stigsdotter Neely, A., Ingvar, M., Magnus Petersson, K., & Bäckman, L. (2006). Cognitive and neural plasticity in aging : General and task-specific limitations. *Neuroscience and Biobehavioral Reviews, 30*, 864-871.

Keys, B. A. (2002). Age-Related deficits in inhibition: Exploring the role of endogenous control. *Dissertation Abstracts International: Section B: The Sciences & Engineering, 63*(10-b).

Kok, A. (1999). Varieties of inhibition : Manifestations in cognition, event-related potentials and aging. *Acta Psychologica, 101*, 129-158.

Zakzanis, K. K., Mraz, R., & Graham, S. (2005). An fMRI study of the Trail Making Test. *Neurosychologia, 43*, 1878-1886.

Kramer, A. F., Humphrey, D, G., Larish, J.F., Logan, G.D., & Strayer, D. L. (1994). Aging and inhibition: Beyong an unitary view of inhibitory processing in attention. *Psychology and Aging, 9*, 491-512.

Kramer, A.F., Larish, J. F., & Strayer, D.L. (1995). Training for attentional control in dual task settings: A comparison of young and old adults. *Journal of Experimental Psychology: Applied, 1*, 50-76.

Kramer, A. F., Larish, J. L., Weber, T. A., & Bardell, L. (1999). Training for executive control, in Gopher and Koriat (Eds.) *Attention and Performance* XVII pp. 617-652, (MIT Press).

Kramer, A. F., & Madden, D. J. (2008). Attention. In F. I. M. Craik and T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp.189-249). New York: Psychology Press.

Kramer, A. F., & Willis, S. L. (2002). Enhancing the cognitive vitality of older adults. *Current Directions in Psychological Science, 11*, 173-177.

Kramer, A.F., & Willis, S. (2003). Cognitive plasticity and aging. In B. Ross (Ed). *Psychology of Learning and Motivation*, vol 43. N.Y.: Academic Press.

Lemercier, C., Ansiau, D., Massioui, F., & Marquié, J. (2003). Vieillissement et attention. *Revue de Psychologie Française, 48*, 89-101.

Levy, J., Pashler, H., & Boer, E. (2006). Central interference in driving : Is there any stopping the psychological refractory period. *Psychological science, 17*, 228-235.

Lezak, M. D., Howieson, D. B., & Loring, D. W. (2004). *Neuropsychological assessment (4th Edition)*. New York: Oxford University Press.

Li, SC., Schmiedek, F., Huxhold, O., Röcke, C., Smith, J., & Linderberger, U. (2008). Working memory plasticity in old age : Practice gain, transfer, and maintenance. *Psychology and Aging, 23*, 721-742.

Logan, G. D. (1994). On the ability to inhibit thought and action: A users'guide to the stop signal paradigm. In D.D. Carr & T.H. Carr (Eds.), *Inhibitory processes in attention, memory, and language* (pp. 189-239). San Diego: Academic.

Lustig, C., Hasher, L., & Zacks, R. (2007). Inhibitory deficit theory: Recent developments in a «new view». In D.S. Gorfein and C.M. Macleod (Ed.), *The place of inhibition in cognition* (pp. 145-162), Washington: American Psychological Association.

Mahncke, H. W., Bronstone, A., & Merzenich, M. M. (2006). Brain plasticity and functional losses in the aged : Scientific bases for a novel intervention. *Progress in Brain Research, 157*, 81- 109.

May, C.P., & Hasher, L. (1998). Synchrony effects in inhibitory control over thought and action. *Journal of Experimental Psychology : Human Perception and Performance, 24*, 363-379.

Maylor, E., Schlaghecken, F., & Watson, D. G. (2005). Aging and inhibitory processes in memory, attentional, and motor tasks. In R.W. Engle, G. Sedek, U. V. Hecker, & D. N. McIntosh (Eds.), *Cognition limitations in aging and psychopathology* (pp. 313-345). Cambridge, Cambridge University Press.

McCrae, C. S., & Abrams, R. A. (2001). Age-related differences in object and location-based inhibition of return of attention. *Psychology and Aging, 16*, 437-449.

McDowd, J. M., & Shaw, R. J. (2000). Attention and aging : A functional perspective. In F. I. M. Craik and T. A. Salthouse (Eds.), *The Handbook of Aging and Cognition* (pp.221-292). New Jersey : Lawrence Erlbaum Associates.

MacDonald, A. W., Cohen, J. D., Stenger, V. A., & Carter, C. S (2000). Dissociating the role of the dorsolateral prefrontal and anterior cingulate cortex in cognitive control. *Science, 288*, 1835-1838.

Melzer, I., Benjuya, N., & Kaplanski, J. (2001). Age-related changes of postural control : Effect of cognitive tasks. *Gerontology, 47*, 189-194.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., & Howerter, A. (2000). The unity and diversity of executive functions and their contributions to complex « frontal lobe » tasks : A latent variable analysis. *Cognitive Psychology, 41*, 49-100.

Moll, J., de Oliveira-Souza, R., Moll, F. T., Bramati, I. E., & Andreiuolo, P. A. (2002). The cerebral correlates of set-shifting : An fMRI study of the trail making test. *Arquivos De Neuro-Psiquiatria, 60*, 900-905.

Nakahachi, T., Ischii, R., Iwase M., Canuet, L., Takahashi, H., Kurimoto, R., Ikezawa, K., Azechi, M., Sekiyama, R., Honaga., E., Uchiumi, C., Iwakiri, M., Motomura, N., & Takeda, M. (2008). Frontal actitivity during the digit-symbol substitution test determined by multichannel near-infrared spectroscopy. *Neuropsychobiology, 57*, 151-158.

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: Views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological Bulletin, 126*, 200-246.

Raz, N. (2000). Aging of the brain and its impact on cognitive performance : integration of structural and functional findings. In F. I. M. Craik and T. A. Salthouse (Eds.), *The Handbook of Aging and Cognition* (pp.1-90). New Jersey : Lawrence Erlbaum Associates.

Roenker, D. L, Cissell, G. M., Ball, K. K., Wadley, V.G., & Edwards, J.D. (2003). Speed-of-processing and driving simulator training result in improved driving performance. *Human Factors, 45*, 218-233.

Rogers, N.L., & Chaparro, A. (2004). Cognitive demands of postural stability in the older adult. *Medecine & Science in Sports & Exercise, 36*, S91.

Royall, D., Chiodo, L. k., Polk, M. J. (2000). Correlates of disability among elderly retirees with subclinical cognitive impairment. *The Journal of Gerontology, 55*, 541-546.

Royall, D. R., Lauterbach, E. C., Cummings, J. L., Reeve, A., Rummans, T. A., Kaufer, D. I., LaFrance, W. C., & Coffey, C. E. (2002). Executive control function: A review of its promise and challenges for clinical research. *The Journal of Neuropsychiatry and Clinical Neurosciences, 14*, 377-405.

Rush, B. K., Barch, D. M., & Braver, T. S. (2006). Accounting for cognitive aging : Context processing, inhibition or processing speed. *Aging, Neuropsychology, and Cognition, 13*, 588-610.

Salomon, G., & Perkins, D. N. (1989). Rocky roads to transfer : Rethinking mechanisms of a neglected phenomenon. *Educational Psychologist, 24*, 113-142.

Salthouse, T. A., & Miles, J. D. (2002). Aging and time-sharing aspects of executive control. *Memory & Cognition, 30*, 572-582.

Sands, L. P., Yaffe, K., Li-Yung L., Stewart, A., Eng, C., & Covinsky, K. (2002). The effets of acute illness on ADL decline over 1 year in frail older adults with and without cognitive impairment. *The Journal of Gerontology Series A : Biological Sciences and Medical Sciences, 57*, M449-M454.

Schmidt, R. A., & Bjork, R. A. (1992). New conceptualizations of practice: common principles in three paradigms suggest new concepts for training. *Psychological Science, 3*, 207-217.

Schooler, C., Neumann, E., Caplan, L., & Roberts, B. (1997). Continued inhibitory capacity throughout adulthood : Conceptual negative priming in younger and older adults. *Psychology and Aging, 12*, 667-674.

Shallice, T. (2002). Fractionation of the Supervisory System. Principes of frontal lobe function. In Stuss, Donald T.; Knight, Robert T. (2002). Principles of frontal lobe function. (pp. 261-277). New York, NY, US: Oxford University Press.

Smith, G. E., Housen, P., Yaffe, K., Ruff, R., Kennison, R. F., Mahncke, H. W., & Zelinski, M. (2009). A cognitive training programme based on principles of brain plasticity: Results from the improvement in memory with plasticity-based adaptative cognitive training (IMPACT) Study. *Journal of the American Geriatrics Society, 57*, 594-603.

Söderlund, H., Nyberg, L., & Nilsson, L.G. (2003). Cerebral atrophy as predictor of cognitive function in old, community-dwelling individuals. *Acta Neurologica Scandinavica*, *109*, 398-406.

Sparrow, W. A., Bradshaw, E. J., Lamoureux, E., & Tirosh, O. (2002). Ageing effects on the attention demands of walking. *Human Mouvement Science, 21*, 961-972.

Stuss, D. T., Bisschop, S. M., Alexander, M. P., Levine, B., Katz, D., & Izukawa (2001). The trail making test : A study in focal lesion patients. *Psychological Assessment, 13*, 230-239.

Stuss, D. T., Shallice, T. Alexander, M. P., & Picton, T. W. (1995). A multidisciplinary approach to anterior attentional functions. In J. Grafman, K. J. Holyoak & F. Boller (Eds.), Structure and Functions of the Human Prefrontal Cortex. (Annals of the New-York Academy of Sciences : Vol. 769, pp.191-211) New-York : New York Academy of Sciences.

Sullivan, M., & Faust, M. (1993). Evidence for identity inhibition during selective attention in old adults. *Psychology and Aging, 8*, 589-598.

Sweeney, J.A., Rosano, C. , Berman, R. A., & Luna, B. (2001). Inhibitory control of attention declines more than working memory during normal aging. *Neurobiology of aging, 22*, 39-47.

Thorndike, E. L., & Woodworth, R. S. (1901). The influence of improvement in one mental function upon the efficiency of other functions. *Psychological Review, 8*, 247-261.

Tomaszewski Farias, S., Cahn-Weiner, D. A., Harvey, D. J., Reed, B. R., Mungas, D., Kramer, J. H., & Chui, H. (2009). Longitudinal changes in memory and executive functioning are associated with longitudinal change in instrumental activities of daily living in older adults. *The clinical neuropsychologist, 23*, 446-461.

Verhaeghen, P., & Cerella, J. (2002). Aging, executive control, and attention : A review of meta-analyses. *Neuroscience and Biobehavioral Reviews, 26*, 849-857.

West, R. L. (1996). An application of prefrontal cortex function theory to cognitive aging. *Psychological Bulletin, 120*, 272-292.

Williams, B.R., Ponesse, J.S., Schachar, R. S., Logan, G. D., & Tannock, R. (1999). Development of inhibitory control across the life span. *Developmental Psychology, 35*, 205-213.

Willis, S. L. (2001). Methodological Issues in Behavioral Intervention Research with the Elderly. In J.E. Birren & K.W. Schaie (Eds.). *Handbook of the psychology of Aging.* Fifth Edition (pp. 78-102). New York: Academic Press.

Woollacott, M., & Shumway-Cook, A. (2002). Attention and the control of posture and gait: a review of an emerging area of research. *Gait and Posture, 16*, 1-14.

Yaffe, K., Fox, P., Newcomer, R., Sands, L., Lindquist, K., Dane, K., & Covinsky, K. E. (2002). Patient and caregiver characteristics and nursing home placement in patients with dementia. *JAMA : the journal of the American Medical Association, 287*, 2090-2097.

Yaffe, K., Petersen, R. C., Lindquist, K., Kramer, J., & Miller, B. (2006). Subtype of mild cognitive impairment and progression to dementia and death. *Dementia and geriatric cognitive disorders, 22*, 312-319.