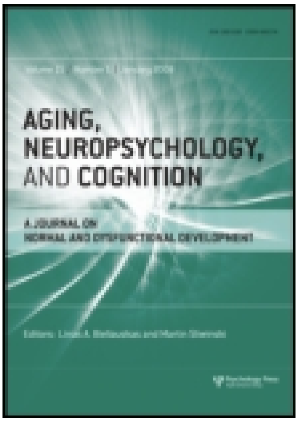

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The Role of Switching, Inhibition and Working Memory in Older Adults' Performance in the Wisconsin Card Sorting Test

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ABSTRACT

The Wisconsin Card Sorting Test (WCST) is considered a typical executive test. However, several interesting questions are still open as to the specific executive processes underlying this task. In the present study, we explored how local and global switching, inhibition and working memory, assessed through the Number–Letter, the Stop Signal and the Reading Span tasks, relate to older adults' performance in the WCST. Results showed that older adults' performance variability in the number of perseverative errors was predicted by the local switch component of the Number–Letter task. Results also showed age-related differences in inhibition, working memory and global switching, while local switching resulted largely spared in aging. This study provides evidence that switching abilities may contribute to performance of older adults in the WCST. It also provides initial evidence suggesting that switching processes, associated with local switch costs, are involved in performance on the WCST, at least in older adults.

Keywords: WCST; Switching; Inhibition; Working memory; Aging.

INTRODUCTION

The Wisconsin Card Sorting Test (WCST; Heaton, Chelune, Talley, Kay, & Curtiss, 1993) is a concept identification task that requires participants to discover – using feedback from the experimenter – how to sort a deck of cards on the basis of four stimulus cards which vary on such parameters as number, color, and shape of symbol. The participant is warned that the rules

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of sorting will change during the experiment. The WCST has long been considered the 'gold standard of executive function tests' (Delis, Kaplan, & Kramer, 2001). The executive functions are broadly defined as *higher order control mechanisms* that can regulate human behavior and cognition (e.g., Stuss & Alexander, 2000). The most frequently postulated executive processes in the literature are suppression of irrelevant information, inhibition of prepotent responses, planning, monitoring, switching, and memory updating (see Stuss, Alexander, & Benson, 1997 for a review). Typically, patients with frontal lesions show impaired performance in a wide range of tasks that are assumed to assess executive functioning, including – among others – the WCST (e.g., Rabbitt, 1997).

Despite the popularity of the WCST as a typical executive test, only recently attention has been devoted to the question of which executive processes are involved in the task. Understanding which specific executive processes are tapped by this complex task is particularly relevant given the increasing amount of evidence supporting the non-unitary nature of executive functioning (Miyake et al., 2000; Rabbitt, Lowe, & Shilling, 2001). For instance, results from neuroimaging studies indicated that executive functions may be fractionated into different component processes and that these components are associated with specific regions of the frontal and posterior parietal cortices (e.g., Collette et al., 2005; Wager & Smith, 2003).

In the literature, the WCST has been more often conceptualized as a switching task because it requires to switch sorting categories after a certain number of successful trials (e.g., Berg, 1948; Nagahama et al., 1996; Vanderploeg, Schinka, & Retzlaff, 1994). Some researchers have, however, argued that the task also requires inhibitory control. Inhibition refers to a broad range of processes that operate to prevent familiar, over-learned or irrelevant information from hampering goal achievement, hence ensuring a coherent and organized behavior (e.g., Dagenbach & Carr, 1994; Friedman & Miyake, 2004). In the WCST inhibition is assumed to suppress the current sorting category in order to switch to new one (e.g., Konishi et al., 1999).

The idea that the WCST may tap switching, inhibition or both abilities was independently tested by Miyake et al. (2000). These authors were mainly interested in understanding the relations among three often-postulated executive functions, i.e., mental set switching, inhibition of prepotent responses, and updating the contents of working memory. They were also interested in examining which of these executive functions are involved in several complex executive and frontal lobe tasks, including, among others, the WCST. Each executive function was assessed using three tasks that are generally believed to involve primarily one of the three target functions. More precisely, the Plus–Minus task, the Number–Letter task, and the Global–Local task were used to tap switching, the Keep Track task, the Tone Monitoring task, and the Letter Memory task were used to tap updating, and finally, the

Antisaccade task, the Stroop task, and the Stop Signal task were used to tap inhibition. Using latent variable analyses (i.e., confirmatory factor analysis and structural equation modeling), Miyake et al. (2000) concluded that, in their sample of younger adults, these three functions, though moderately correlated, were separable and contributed differently to performance on complex executive and frontal lobe tasks. In particular, switching was found to be the best predictor of WCST performance. Such a finding suggests that, in normal younger subjects, individual differences in WCST performance are mainly determined by switching abilities.

The purpose of the present investigation is to explore how switching and inhibition contribute to performance in the WCST in older adults. It is relevant to note that earlier studies primarily focused on age-related differences in the WCST. Robust age differences in performance in this task (especially in the number of perseverative errors) were reported several times (e.g., Rhodes, 2004) and were generally attributed to changes in prefrontal lobe functions (Tisserand & Jolles, 2003; West, 2000). Some earlier studies also focused on identifying the cognitive processes responsible for the age differences in the WCST. For instance, reduced working memory (Hartman, Bolton, & Fehnel, 2001) and general cognitive slowing (Fristoe, Salthouse, & Woodard, 1997; Salthouse, Fristoe, & Rhee, 1996) have been advocated as being responsible for the age-related differences in performance in the WCST. However, the precise nature of the executive processes involved in older adults' performance in the WCST has remained largely unexplored (also see Rhodes, 2004).

It is important to identify the executive processes tapped by this task in older adults as it seems plausible that in the elderly the WCST relies on different processes as compared to younger adults. In fact, Miyake et al. (2000) acknowledged that their results obtained with younger college students may not be completely generalizable to cognitively diverse samples, such as those that include older adults. Indeed, given the obvious complexity of the WCST, there are many ways to pass (or fail) this test, and so one might expect multiple processes and brain areas to be involved in performance on this task (Kane & Engle, 2002). This suggests that older adults may adopt different strategies to perform the task, possibly as a result of a specific pattern of age-related changes or neurological alterations in frontal or other brain areas. This speculation is indirectly supported by additional evidence of the WCST's low specificity. In fact, although clinical experience and early research supported the use of the WCST as a diagnostic tool for assessing frontal cortex damage, more recent data provide mixed support for an association between performance in the WCST and frontal cortex (for reviews, see Mountain & Snow, 1993; Reitan & Wolfson, 1994). For instance, relative to patients with posterior damage, patients with frontal cortex damage are sometimes unimpaired (see, e.g., Anderson, Damasio, Jones, & Tranel, 1991;

Corcoran & Upton, 1993; Grafman, Jonas, & Salazar, 1990) and sometimes impaired (see, e.g., Drewe, 1974; Milner, 1963; Nelson, 1976) in the WCST. Furthermore, it is interesting to note that, like frontal lobe patients, older adults generally show an overall decrement in performance, including an increase in perseverative errors. However, as noticed by Hartman et al. (2001), there is evidence indicating that, unlike frontal lobe patients, older adults show high correlations between perseverative and non perseverative errors, with similar increase in the two types of errors. Furthermore, frontal lobe patients show an increase in previous category perseverations whereas older adults do not. Thus, older adults' performance in the WCST differs in some way from that of neurological patients with frontal lobe damage. This is likely to occur because the underlying neuroanatomical changes also differ, providing further support to the hypothesis that there are different ways to perform this complex task.

To assess the contribution of switching performance in the WCST we considered two types of switch costs, derived from participants' performance in the Number–Letter task (adapted from Rogers & Monsell, 1995). This task, which will be better described in the Method section, involves single-task blocks, in which participants have to classify letter or number characters, and mixed-task blocks (switch and non-switch trials), in which participants have to alternate responses to the letter and to the number. Switch costs can be assessed at a specific level within mixed-tasks blocks as the difference between response times in switch trials and in non-switch trials, hereafter termed 'local switch costs'. Reconfiguration theories attribute these costs of switching to the reconfiguration of task settings at trial-to-trial transitions (e.g., Meiran, 1996; Rogers & Monsell, 1995). Alternatively, interference theories propose that local switch costs are substantially or wholly attributable to a conflict arising from memory due to the recent performance on a different task (e.g., Allport & Wylie, 1999).

At a more general level, switch costs can be calculated as either the difference between response times in mixed-task blocks and in single-task blocks (e.g., Kray & Lindenberger, 2000; Kray, Li, & Lindenberger, 2002; Mayr, 2001), often referred to as 'global switch costs', or as the difference between response times in no-switch trials from the mixed-task blocks and in single-task blocks (e.g., Kray, 2006; Rubin & Meiran, 2005), often termed 'mixing costs'. Theoretically, the task switching literature does not differentiate between these two measures. Furthermore, the terms global and mixing costs are interchangeably used. In order to avoid misunderstandings, in the present study, we will use the broader term 'general switch costs' to refer to the costs of switching derived at a block level of analysis, independently from the specific difference score used to calculated them (global or mixing).

At first, general switch costs were attributed to higher memory load in mixed-task blocks because two tasks have to be kept active in working memory (e.g., Kray & Lindenberger, 2000). More recently, however, Rubin and Meiran (2005) suggested that general costs cannot be explained by simply assuming a higher memory load in mixed blocks. Rather, their results supported the hypothesis that mixed-tasks blocks require the resolution of task conflict by showing that general costs existed only with overlapping or bivalent stimuli (i.e., stimuli that allow both tasks to be performed) but not with univalent stimuli (i.e., stimuli that allow only one task to be performed). The authors acknowledged that bivalent stimuli have dual affordances and, as a result, can activate the incorrect task and/or response in addition to activating the correct one and thus can cause interference (e.g., Ruthruff, Remington, & Johnston, 2001).

Although both switch costs assessed at a specific level and at a general level reflect the costs derived from alternating between multiple response sets, there is evidence indicating that these types of task switching components involve different processes (e.g., Braver, Reynolds, & Donaldson, 2003; Dove, Pollmann, Schubert, Wiggins, & von Cramon, 2000; Kray, 2006). For instance, there is evidence indicating that these task switching components are separable into two distinct but intercorrelated latent factors (Kray & Lindenberger, 2000). Furthermore, brain imaging studies found that general and local switch costs are associated with activation patterns in separate brain regions (e.g., Braver et al., 2003; Crone, Wendelken, Donohue, & Bunge, 2005). Therefore, it appears important to assess whether both task switching components contribute to performance on the WCST, which requires one to keep various sorting rules active in working memory as well as to activate new relevant response rules and deactivate previously relevant ones. In this respect, it is important to note that Miyake et al. (2000) did not differentiate between local and general switch costs. Furthermore, they assessed the switch costs in different ways across the three switching paradigms selected to tap the switching function. Specifically, in the Plus–Minus task and in the Local–Global task they calculated global and local switch costs, respectively. In the Number–Letter task (which was the same as the task used in the present study) they calculated the costs of switching as the difference between response times in switch trials from the mixed-tasks blocks and response times in single-task blocks. This is an atypical measure, for which, to the best of our knowledge, there is no other reference to in the current literature. These different switch costs were used to extract the factor corresponding to the switching function, which was then used in structural equation modeling to examine how it contributed to performance on the WCST. Therefore, although Miyake et al.'s results clearly indicate that switching abilities are involved in the WCST, they do not allow to ascertain which task switch component (local or general) is the best predictor of performance on this complex task. We therefore advocate the necessity to be more specific when discussing and measuring switching abilities.

To assess the contribution of inhibitory performance in the WCST we considered the stop signal response time (SSRT), which indicates the speed of the inhibition process operating in a Stop Signal task (Logan, 1994). In this task, which will be better described in the Method section, participants are presented with stimuli whose identity designates a speeded response. On few occasions, however, the stimulus is followed (at some variable intervals) by a stop signal that advises the subject to withhold that response. Authors generally agree that suppression of a pending response is one of the best-defined types of inhibitory control processes (Band, van der Molen, & Logan, 2003) and that it is essential to adjust one's actions dynamically when unanticipated changes in the environment suddenly make ongoing actions inappropriate (e.g., Ridderinkhof, Band, & Logan, 1999). With respect to inhibition, many definitions and taxonomies have been proposed to describe inhibitory control processes (but see MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003 for a different view). Reflecting these differences in definitions, a number of tasks have also been used to tap these processes, ranging from simple tasks, such as the suppression of reflexive responses (e.g., the antisaccade task, Everling & Fischer, 1998), to more cognitively demanding tasks, such as the directed forgetting task (Bjork, 1989). One commonality among the various types of inhibitory control processes is that all seem to require some degree of executive control in performing the representative tasks, which is supposed to involve the frontal lobes. However, there is evidence indicating that different inhibitory tasks do not correlate among each other, as it could be expected if one assumes that different inhibitory tasks measure the same construct (e.g., Borella, Carretti, & De Beni, 2008; Friedman & Miyake, 2004). Recently, some theorists proposed that inhibitory control processes correspond to a family of relatively independent functions rather than to a single unitary construct under the more general rubric of executive functions. For instance, Friedman and Miyake (2004), using confirmatory factor analyses, found that Prepotent Response Inhibition and Resistance to Distractor Interference were closely related, but both were unrelated to Resistance to Proactive Interference. There is also evidence that there are multiple inhibitory systems and processes in the central nervous system that may be expressed in many different ways (e.g., Kok, 1999).

In the present investigation, we also aimed to assess whether working memory capacity contributes to older adults' performance in the WCST. To this purpose, we considered the working memory capacity, assessed using the Reading Span task (Daneman & Carpenter, 1980). It is well known that working memory plays a crucial role in various cognitive complex abilities and tasks that require the temporary storage and processing of information (e.g., Borella, Carretti, & Mammarella, 2006; De Beni & Palladino, 2004). The manipulation and maintenance of information is, thereby, also required in performing the WCST, in that completed sorts have to be maintained in memory while new information is processed in order to determine how to sort each card (e.g., Kimberg & Farah, 1993). As indicated earlier, previous studies have focused on the role of older adults' reduced working memory capacity as a mediating factor of age-related differences in performance on the WCST (Fristoe et al., 1997; Hartman et al., 2001). However, the contribution of working memory to within-group inter-individual differences in performance has remained largely unexplored. Some indirect evidence that working memory may contribute to performance in the WCST comes from a study by Hartman, et al. (2001 – Experiment 1). By adopting a new scoring system, these authors classified the errors (perseverative and non-perseverative) produced in the WCST as having a high or a low processing load according to whether they occurred after an incorrect or a correct sort, respectively. Furthermore, they also classified the errors as occurring under high or low memory load, according to whether the immediately preceding sort contained sufficient information to select the correct rule. This scoring system derived from the authors' assumption that, when a new rule has to be selected, more processing load is necessary following an incorrect versus a correct sort because one must evaluate and choose among alternative possibilities. Another assumption was that memory load is higher whenever information from more than one previous sort is important in determining the current sorting rule. Results obtained through this new scoring system showed that errors were more frequent, for both younger and older adults, whenever information from multiple previous sorts was needed and processing demands required the selection of a new rule, therefore supporting the concept that the WCST is sensitive to working memory demands.

To summarize, the present study aimed to determine how local switching, general switching and inhibition relate to older adults' performance in the WCST. Switching and inhibition were evaluated by means of the Number–Letter task (adapted from Rogers & Monsell, 1995) and the Stop Signal task (Logan, 1994), respectively. An additional aim of the present study was to explore more directly whether and, if so, to what extent, inter-individual differences in older adults' working memory capacity, assessed in the present study by means of the Reading Span task (Daneman & Carpenter, 1980), contribute to performance in the WCST.[1]

[1]Miyake et al. (2000) examined the extent of unity or diversity of different executive functions and how each target executive functions contributed to performance on a number of complex executive tasks (including, among others, the WCST) at the level of latent variables. In the present study switching, inhibition and working memory were analyzed at the level of manifest variables (i.e., individual tasks) because we could not recruit enough participants available at performing more domain-specific tasks, necessary to define latent variables.

METHOD

Participants

Forty older Italian adults participated in this study. A group of forty younger Italian adults was also included in the present study as a control to ensure that older adults' performance in the WCST and in the other experimental tasks included in the present study conformed to the previously documented age-related trends on these tasks. Within the younger adults group, aged 21 to 36, most participants were recruited from local sport and cultural centres. Only few younger adults were university students. Older adults, aged 60 to 79, were healthy community dwelling individuals recruited from local associations. Individuals with a history of neurological and psychiatric disorders, who were assuming psychoactive pharmacological treatments that could alter cognitive performance, as well as older adults with a score less than 26 on the Mini Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975), were excluded from the study. Both younger and older adults participated in this experiment as volunteers. All participants had normal or corrected-to-normal vision and were non-colorblind. Participants characteristics are presented in Table 1.

Older adults had a medium level education,[2] though lower than younger adults, $t(78) = 8.17$, $p < .01$. Moreover, older adults had a significantly poorer performance on the Raven Colored Progressive Matrices (Raven, Court, & Raven, 1995), included in the present investigation as an index of fluid intelligence, $t(78) = 2.8$, $p < .01$, than younger adults. Despite age differences in the Raven's test, this measure of fluid intelligence did not correlate with performance on the WCST.

TABLE 1. Means and Standard Deviations of Participants' Years of Education Completed, Mini Mental State Examination (MMSE) and Raven Coloured Progressive Matrices (RCPM) Scores

	Young		Old	
	M	*SD*	*M*	*SD*
Age	29.2	4.1	67.8	5.0
Education*	14.5	.1	10.1	2.7
RCPM*	32.9	2.5	30.7	3.9
MMSE	/	/	29.5	0.8

*$p < .01$.

[2]Eight years of education represent the end of the compulsory education cycle in Italy.

Tasks

Wisconsin Card Sorting Test

The WCST consisting of 128 cards was used in this study (Heaton, 1981). Each card displayed one of four possible shapes (star, triangle, circle and cross), varying in number (1 to 4) and in color (green, yellow, blue and red). Each participant was presented with the same sequence of cards. Four key cards, representing, respectively, one red triangle, two green stars, three yellow crosses and four blue circles, were placed in front of participants. Participants were informed that the purpose of the task was to use these four cards as a guideline to discover the rule to sort the remaining cards. The sorting rule was changed after 10 consecutive correct sorts without informing the participant who had to discover each new sorting strategy by using exclusively the experimenter's feedback about the appropriateness of each sorting. The order of sorting rules was the same for each participant (color, form, number, color form, number). The test terminated when six sorting categories were completed or when all cards were used. A variety of different dependent measures are available for this task. In the present report, we will mainly focus on perseverative errors. These errors are unambiguously wrong responses that derive from the persistence in using the previous sorting principle after receiving feedback from the experimenter that indicated that the preceding sorting principle was no longer valid. This is the measure from the WCST which is often considered the most sensitive to frontal lobe dysfunction (e.g., Hedden & Yoon, 2006; Zelazo, Craik, & Booth, 2004; Fristoe et al., 1997; Kramer, Humphrey, Larish, Logan, & Strayer, 1994; Raz, 2000; Salthouse et al., 1996).

Number–Letter Task

This task is the same as that used by Miyake et al. (2000) and was adapted from Rogers and Monsell (1995). It requires participants to classify either the digit number of a pair of characters as even/odd, or the letter member as a consonant/vowel according to whether the pair appears in the top or in the bottom quadrants of a 10-cm squared framework presented in the middle of the computer screen. There are three blocks of trials. In the first two blocks of 64 trials each, the pair of characters appears alternatively in the two top quadrants and in the two bottom quadrants. In the third block of 128 trials, the pair of characters progressively appears in all four quadrants following a clockwise rotation. Thus, the trials in the first two blocks require no switching, whereas half of the trial in the third block require participants to switch the categorization mode at predictable positions. In the present study, the number–letter pairs were constructed randomly coupling the consonant M, K, G, R and the vowel A, E, I, U with the odd number 3, 5, 7, 9 and the even number 2, 4, 6, 8. Each character pair was displayed in an uppercase Times font 26 and remained in view until the participant pressed the response key (letter P for even numbers and vowels and letter Q for odd numbers and consonants) or until 4000 ms had elapsed. The inter-trial interval was set at 200 ms. Participants were instructed to respond as quickly as possible while avoiding errors. Each block started with 10 practice trials, which could be repeated if required by the participant. The dependent measures for this task were (a) the local switch cost, i.e., the difference between trials from the third block in which participants had to switch (i.e., from the top right to the bottom right quadrant and from the bottom left to the top left quadrant) and trials from the same block in which no switch was required (i.e., from the top left to the top right quadrant and from the bottom right to the bottom left quadrant), (b) the global switch costs, i.e., the difference between the first two blocks, in which participants performed just one type of categorization, and the third block, in which participants alternated between the two types of categorization (e.g., Koch, Prinz, & Allport, 2005; Los, 1996), and (c) the mixing costs, i.e., the difference between the first two blocks, in which participants performed just one type of categorization, and the trials from the third block in which no switch was required (e.g., Kray & Lindenberger, 2000; Meiran, 2000; Rubin & Meiran, 2005).

Stop Signal Task

The Stop Signal task used in the present study was modeled after the one used by Williams, Ponesse, Logan, Schachar, and Tannock (1999). It consists of two concurrent tasks, a go task and a stop task, both based on a response-compatibility task (Eriksen & Eriksen, 1974), requiring participants to respond to the central target letter of three letters array, while ignoring the two flanker letters. The go task consisted in one block of 96 trials and served to build up a prepotent response in the compatibility task. The subsequent stop task, consisting in two blocks of 67 trials each, was the same as the go-task except that a stop signal, a 1000-Hz, 65-dB tone (100 ms duration), was added on 25% of the trials. Participants were instructed to perform the task as they did before but to withhold their response whenever they heard the stop signal. They were also forced to respond as quickly as possible without delaying the response in anticipation of the stop signal. The letters used in this task were X, Y, C and S. Participants were instructed to press two different keys according to whether an X or a Y (letter L) or a C or an S (letter A) were the target letters. Only incompatible response trials, i.e., target letter always flanked by two letters with incompatible responses, were included in the present study. All trials started with a 500-ms fixation cross, followed by a three-letter array, which remained on the screen until the response was given or until 1000 ms had elapsed; the inter-trial interval was fixed at 700 ms. The time interval between the presentation of the letters array and the presentation of the stop signal in the stopping trials was set by a tracking procedure (Logan, Schachar, & Tannock, 1997). More precisely, the initial stop signal delay, that was set at 250 ms, was increased (making it harder to inhibit) or decreased (making it easier to inhibit) by 50 ms after every stop signal trial, according to whether participants succeeded or failed in inhibiting their response. This tracking procedure compensates for individual (and group) differences in go response times (Logan et al., 1997) converging on a mean Stop Signal Delay at which participants successfully inhibit their response on 50% of the stop signal trials. This delay (stop delay) represents the average point in time at which the stop process finishes. The dependent variable for this task was the stop signal response time (SSRT), which represents the primary performance variable in the stop signal task and indicates the speed of the inhibition process. It is calculated as the difference between the mean response time in the go trials (GoRT) and the mean stop delay (see Logan et al., 1997, for more details about the tracking procedure and the measurements of processes involved in the Stop Signal task).

Reading Span Task

This complex span task (Daneman & Carpenter, 1980) requires participants to read sentences aloud while remembering the sentence-final words. An Italian version of this task was used in the present investigation (Pazzaglia, Palladino, & De Beni, 2000). Sixty unrelated sentences, 12 to 16 words in length, were created and were arranged in 5 sets containing three groups of two, three, four, five and six sentences, respectively. Sentences were individually printed, in Times font 22, on cards that were shown one at a time to the participant. Participants were required to read aloud each sentence and to recall the last word of each sentence, in the order they had occurred, at the end of each study trial, marked by a blank card. Participants were presented with increasingly longer sets of sentences until they failed all three groups at a particular level. The dependent variable for this task was the span level, calculated following Daneman and Carpenter's (1980) scoring procedure. More precisely, the span level was defined as the set at which a participant correctly recalled all last words two out of three times; if a participant was correct on only one group at the level higher than his span level, he/she was given a credit of 0.5.

Procedure

The experimental tasks were administrated in two sessions, after an initial meeting during which participants were informed on the purpose of the investigation and performed the MMSE and the Raven Coloured Progressive Matrices test. The order of task administration was the same for all participants and was chosen to minimize tiredness. The WCST and the Stop Signal task were administered during the first meeting. The Number–Letter task and the Reading Span task were administrated during the second meeting, which occurred about two days after the first meeting. On average, both testing sessions lasted about 1 h.

RESULTS

Means, standard deviations and the *t*-tests for age group differences on the number of perseverative errors in the WCST and on the three experimental tasks (Number–Letter, Stop Signal and Reading Span) are illustrated in Table 2. Table 2 also presents the correlations between the relevant dependent measures and age, and the correlations between these measures and age after controlling for speed of responding, as indicated by participants' response times in the first two blocks of the Number–Letter task. In line with an extensive literature showing a general slowing during aging (e.g., Salthouse, 1996), older adults were significantly slower than younger adults in the Number–Letter and in the Stopping tasks, in which performance was assessed through response times. In line with previous findings (Rhodes, 2004), significant age differences were also found in the number of perseverative errors, favoring younger adults. The finding of a non-significant partial correlation between age

TABLE 2. Means, Standard Deviations and the *t*-Tests for Age Group Differences on the Number of Perseverative Errors in the WCST and on the Three Experimental Tasks

	Young		Old				
	M	*SD*	*M*	*SD*	*t*-Test	Age *r*	Age r_{speed}
WCST							
Perseverative errors	9.65	6.57	12.83	6.95	–2.10*	.22*	.16
Number–letter task							
Single-task blocks – No Switch Trials RT (ms)	738.71	102.80	1107.91	277.61	–7.88 ***	–	–
Mixed-task block – No Switch Trials RT (ms)	863.00	169.14	1531.35	492.70	–8.11***	–	–
Mixed-task block – Switch Trials RT (ms)	1364.45	340.08	2208.71	721.15	–6.70***	–	–
Global Costs	375.02	183.42	762.11	427.93	–5.26***	.55***	.26*
Mixing Costs	124.30	127.12	423.44	332.76	–5.31***	.55***	.32**
Local Costs	501.4	264.1	677.4	372.8	–2.43**	.28**	.02
Stop Signal task							
GoRT	543.30	54.83	656.38	119.20	–5.45***	–	–
SSRT	271.24	45.79	367.01	114.414	–4.91***	.53***	.42***
Stop Delay	453.14	94.98	391.41	147.19	2.23**	–	–
Reading Span task	3.46	0.68	2.75	0.44	5.58***	–.53***	–.35**

Note. Age *r* = correlations between the relevant dependent measures and age; Age r_{speed} = correlations between the relevant dependent measures with age, after controlling for speed of responding; GoRT, Go Response Time; SSRT, Stop Signal Response Time. ***$p < .001$; **$p < .01$; *$p < .05$.

and perseverative errors, after controlling for speed of responding, suggests that age-related differences in the WCST are mediated by age-related reduction in processing speed (Fristoe et al., 1997; Salthouse et al., 1996). Age trends favoring younger adults were also found for the working memory measure and for the SSRT. More precisely, in line with previous findings, older adults showed significantly poorer performance in the Reading Span task (e.g., Verhaeghen, Marcoen, & Goossens, 1993) and significantly larger SSRT in the Stop Signal paradigm (see Bedard et al., 2002; Kramer et al., 1994, for similar results) than younger adults. It is unlikely that age-related general slowing can account for older adults' larger SSRT given that the tracking procedure used in the Stop Signal task corrects for individual and group differences in the response times distribution (Logan et al., 1997). This conclusion is supported by the finding of significant correlations between age and SSRT, even after controlling for age-related general slowing.

With respect to the Number–Letter task, the local switch costs, the global switch costs and the mixing costs were significantly larger in older adults than in younger adults. However, the relative size of the local switch cost, calculated as a proportional increase in response times in the switch trials from the third block as compared to response times in the no-switch trials from the same block, was similar in younger and older adults (younger adults = 59.2%, older adults = 46.6%, $t(78) = 1.9$). On the other hand, the relative size of the global switch cost, which was calculated as a proportional increase in response times in the third block, in which participants alternated between the two types of categorization, as compared to response times in the first two blocks, in which participants performed just one type of categorization, remained significantly larger in older than in younger adults (younger adults = 50.7%, older adults = 69.3%, $t(78) = -2.9$, $p < .01$). Also, the relative size of the mixing cost, which was calculated as a proportional increase in response times in trials from the third block in which no switch was required, as compared to response times in the first two block, in which participants performed just one type of categorization, remained significantly larger in older than in younger adults (younger adults = 16.9%, older adults = 38.6%, $t(78) = -4.2$, $p < .001$).

Correlational analyses were conducted in older adults to examine the extent to which perseverative errors in the WCST are related to the following measures: switching (indexed by global switch costs, mixing costs and local switch costs obtained in the Number–Letter task[3]), inhibition (indexed by the SSRT, obtained in the Stop Signal task), and working memory

[3]Global switch costs, mixing costs and local switch costs calculated without taking into account the age-related differences in speed were used in this and in the following analyses as they were conducted separately for the two age groups and the effect of the age-related general slowing was therefore no more relevant.

(indexed by the span score obtained in the Reading Span task). Correlations were computed separately for younger and older adults given that, as indicated earlier, it may be the case that different executive functions differ, in cognitively diverse samples, in their level of separability and they may therefore differently contribute to performance on complex executive tasks. These differences may however be obscured when the relations between the various measures are examined through the different age groups. As illustrated in the correlation matrix (Table 3), in both age groups the highest correlations were found between the switch costs obtained in the Number–Letter task, except between the mixing costs and the local switch costs. These were the only significant correlations in the group of younger adults. In the group of older adults, perseverative errors from the WCST significantly correlated with local switch costs from the Number–Letter task and with the span score from the Reading Span task. Furthermore, local switch costs, but not global switch and mixing costs, significantly correlated with the working memory measure. The measure of inhibition did not correlate with any of the other task measures. Therefore, older adults who showed lower local switch costs produced fewer perseverative errors and had a higher working memory span, as compared to older participants who showed larger local switch costs.

To determine which variables better account for older adults' performance on the WCST test, a stepwise multiple-regression analysis was conducted with the number of perseverative errors as the dependent variable and with the span measure, the inhibition measure, the mixing costs and the local switch costs as independent variables.

TABLE 3. Correlation Matrix for Younger (Numbers in the Bottom Left Half) and Older Adults (Numbers in the Top Right Half)

	1	2	3	4	5	6
1. WCST Perseverative errors	–	.27	.08	.49**	–.07	–.35*
2. Switching Global Costs	–.24	–	.91***	.67***	.17	.31
3. Switching Mixing Costs	–.20	.70***	–	.30	–.17	–.09
4. Switching Local Costs	–.14	.72***	.00	–	.08	–.56**
5. Inhibition SSRT	–.18	–.16	–.09	–.14	–	–.01
6. Working Memory Reading Span Test	–.11	–.16	.08	.14	–.04	–

Note. WCST = Wisconsin Card Sorting test. SSRT = Stop Signal Response Time.
***$p < .001$; **$p < .01$; *$p < .05$.

We decided to include the mixing costs and the local switch costs in the regression analysis because non-significant correlations were found between these switch costs. Therefore, their inclusion in the regression analysis allowed to avoid collinearity between global and local switch costs. Results from the regression showed that, together, the predictors accounted for a significant part of the variance in the number of perseverative errors, $R^2 = .24$, $p < .001$. Furthermore, the measure of local switch costs was the only salient predictor as it made a unique contribution to the explained variance in the WCST score, $\beta = .49$, $p < .001$. The working memory span measure, the inhibition measure, and the measure of mixing costs did not contribute significantly to any additional variance.[4] Multiple-regression analyses were not computed for younger adults since non-significant correlations among performance on the WCST and the measures of switching, inhibition and working memory were found.

DISCUSSION

The main purpose of the current study was to ascertain which specific abilities are tapped by the WCST when older adults' performance is considered. In particular, the study was aimed at assessing whether older adults' performance in the WCST may be accounted for by two frequently postulated executive functions often assumed to be involved in this complex task., i.e., switching and inhibition. These functions were assessed in this study through the Number–Letter task and the Stop Signal task, respectively. Moreover, given that there are some indirect evidence that the WCST may be sensitive to working memory demands, we also included in the present investigation a working memory measure, the Reading Span task, to explore more directly whether working memory capacity contributes to older adults' performance in the WCST.

Given that a group of younger adults was included in the present study as a control, it was possible to assess age-related trends in the tasks included in the study. In line with an extensive cognitive aging literature (see Rhodes, 2004), significant age differences, favoring younger adults, were found in the number of perseverative errors. Consistent with previous research, results also indicated that older adults scored significantly lower in the Reading Span task as compared to younger adults (e.g., McCabe & Hartman, 2003; Verhaeghen et al., 1993). In the Stop Signal task, older adults showed larger

[4]Given that processing speed is an important mediator of older adults' cognitive performance, following the suggestion of an anonymous reviewer, we separately run a stepwise multiple-regression analysis including also the processing speed measure as another independent variable to determine whether older adults' performance in the WCST can be explained, at least partially, by processing speed. The results did not change and local switch costs remained the best predictor.

SSRT than younger adults. This result is in line with the findings of earlier studies indicating a marked slowing on SSRT throughout adulthood (Bedard et al., 2002; Kramer et al., 1994; but see Williams, et al., 1999, for different results) and, more generally, with a substantial literature indicating age-related changes in inhibitory control on a variety of cognitive tasks. For example, older adults were found to have more difficulty than younger adults in ignoring distracting material in visual selective attention tasks, in speeded classification tasks (e.g., Hartley, 1992; Kok, 1999), and during language processing (e.g., Li, Hasher, Jonas, May, & Rahhal, 1998). There is also some evidence indicating that older adults are less able than younger adults to suppress no longer relevant information (e.g., Borella et al., 2008; Hamm & Hasher, 1992) and to activate more information in response to a target stimulus that is not directly relevant to that particular stimulus (e.g.. Gerard, Zacks, Hasher, & Radvansky, 1991). These results have been important for one of the most influential theories of cognitive aging suggesting that aging is mainly characterized by a generalized breakdown in inhibitory control (Hasher & Zacks, 1988; Zacks & Hasher, 1994). It is however important to note that there is also evidence indicating that older adults perform as accurately as younger adults on some cognitive tasks that have been conventionally assumed to tap different forms of inhibition. For example, a meta-analytic review concluded that both younger and older adults show a reliable and equivalent negative priming effect (Gamboz, Russo, & Fox, 2002), which is considered by many to be a direct marker of attentional inhibition (e.g., Tipper, 2001). There is also evidence of age-related equivalence in the directed forgetting effect (Gamboz & Russo, 2002; Sego, Golding, & Gottlob, 2006; Zellner & Bäuml, 2006), which is assumed to derive from retrieval inhibition (e.g., Bjork, 1998). These results seem therefore to challenge the theoretical position suggesting that there is a generalized breakdown in inhibitory control during aging. It is however important to acknowledge that alternative non-inhibitory accounts of the negative priming effect (e.g., Milliken, Joordens, Merikle, & Seiffert, 1998) and of the directed forgetting effect (e.g., Sahakyan & Delaney, 2003) have been proposed. Therefore, given the current difficulty in pinpointing the precise mechanism supporting these effects, the question of whether aging is accompanied by a generalized deficit in inhibitory mechanisms still remains an ongoing debate.

With respect to the Number–Letter task, older adults showed larger global switch costs, mixing costs and local switch costs, as compared to younger adults. However, in line with the findings of earlier studies (e.g., Bojko, Kramer, & Peterson, 2004; Kray & Lindenberger, 2000; Mayr & Liebscher, 2001; Salthouse, Fristoe, McGuthry, & Hambrick, 1998; van Asselen & Ridderinkhof, 2000; Verhaeghen & Cerella, 2002; but see De Jong, 2001; Kray et al., 2002; Meiran, Gotler, & Perlman, 2001), the age-related differences in local switch costs disappeared once baseline differences in speed were taken into account. On the other hand, global switch and mixing costs remained significantly larger in older than in younger adults even after the age-related differences in speed were taken into account, replicating previous results (e.g., Cepeda, Kramer, & Gonzalez de Sather, 2001; Kray & Lindenberger, 2000; Mayr & Liebscher, 2001; Meiran et al., 2001; van Asselen & Ridderinkhof, 2000; Verhaeghen & Cerella, 2002; for different results see Kray et al., 2002; Mayr, 2001; Mayr & Kliegl, 2000). It has been suggested that age-related differences in global switch and mixing costs result from older adults' decreased ability to efficiently maintain competing task sets in working memory (e.g., Kray & Lindenberger, 2000). In this respect, it seems relevant to notice that, in this study, local switch costs, but not global switch and mixing costs, significantly correlated with the working memory measure. The lack of significant correlations between both global switch costs and mixing costs and working memory may suggest that the switch costs emerging at a general level are determined, at least in the Number–Letter task used in this study (which, to the best of our knowledge, has never been used with older adults), by task conflict, as recently suggested by Rubin and Mairan (2005), rather than by larger working memory load in the mixed-tasks blocks. The stimuli of the task-switch paradigm used in the present study consisted of pairs of characters made up by a letter and a number. These may be considered bivalent stimuli (following the definition of Rubin & Meiran, 2005) given that they allow both categorization tasks (of the letter as a consonant/vowel and of the number as even/odd). According to Rubin and Meiran (2005), these kinds of stimuli can cause interference by activating both the correct and the incorrect task and/or response. This interference may be more difficult to resolve for older than for younger adults. Given that we found non-significant correlations between both global switch costs and mixing costs and the SSRT, it may be argued that the kind of interference caused by bivalent stimuli in a switching paradigm is different in nature from the interference arising, in a stop signal task, by the pending response.

The significant correlation we found between local switch costs and working memory is difficult to accommodate within the hypothesis that local switch costs reflect specific or transient control mechanisms operating at trial-to-trial transitions (Allport & Wylie, 1999; Meiran, 1996; Rogers & Monsell, 1995). However, one may account for this correlation by assuming that it is the Reading Span task that depends, at least in part, on switching abilities. To date, some researchers have pointed out that the ability to efficiently shift back and forth between the processing and storage requirements of complex working memory span tasks, like the Reading Span task, may be crucial for, or at least plays an important role in, performance on these tasks (e.g., Conway & Engle, 1996).

As regards the switch costs results, a further consideration is in order. In both age groups, global and mixing costs were highly correlated, but only global switch costs significantly correlated with local switch costs. This pattern of correlations seems to suggest that global and mixing costs capture different aspects of the mechanism responsible for the costs of switching emerging at a block level, contrary to the implicit assumption that they measure the same thing. As already stated in the Introduction, so far global and mixing costs have never been disentangled on a theoretical ground. When either term was used, this choice was never justified. Furthermore, to the best of our knowledge, no previous studies considered the correlation between these two measures. Our results may therefore offer new directions for future task switching research to disentangle the common from the specific sources, as well as the mechanisms, explaining global and mixing costs.

With respect to the main purpose of this study, correlational analyses indicated that, in the group of older adults, working memory capacity, as measured by the Reading Span task, and local switch costs, as measured by the Number–Letter task, significantly correlated with the number of perseverative errors in the WCST. Furthermore, results from multiple-regression analyses indicated that older adults' variability in the number of perseverative errors was best predicted by local switch costs.

Before drawing any conclusion from the present results, an important consideration is in order. Significant correlations and, in particular, the correlation between local switch costs and perseverative errors, were only found for older adults. Therefore, one might object that the lack of the same relationship for younger adults is contrary to Miyake et al.'s results (2000) and that this may cast some doubts on the relationship found for older adults. While we are aware of the difficulty to provide a clear-cut explanation for the difference between the patterns of correlations found in younger and older adults, we can suggest two considerations. First, the overall pattern of low and not-significant zero-order correlations we found in this study for younger adults is not surprising. Miyake et al. (2000) found quite low and generally non-significant correlations between different executive measures, at the level of manifest variables, in their group of college students (e.g., switch costs in the Number–Letter task-perseverative errors, r = .13; SSRT-perseverative errors, r = –.01; Operation Span task-perseverative errors, r = .16; switch costs in the Number–Letter task-SSRT, r = .13; switch costs in the Number–Letter task-Operation Span task, r = .08; SSRT-Operation Span task, r = .13). The relation between switching abilities and the WCST (and, more in general, between the different executive processes they considered in their study) emerged only when the authors defined the latent variables from the tasks selected to tap the different executive functions and tested the hypotheses as to whether switching is involved in performance in the WCST by means of structural equation modeling. Miyake et al. (2000) claimed that, analyzing the data at the level of latent variables may have increased the chance of revealing the underlying commonality of different tasks assumed to tap a putative executive function, which may otherwise be obscured by tasks impurity problems.[5] Therefore, the failure to find significant correlations for younger adults at the manifest level for individual tasks is neither unexpected nor in opposition with results of Miyake et al. (2000). Second, it is reasonable to speculate that the commonality of different tasks assumed to tap a putative executive function may emerges more easily in older adults, leading to significant correlations (as in the present study) because, in late life, cognitive abilities become less distinctive and discernable, yielding to less heterogeneous patterns of cognitive performance. This phenomenon, known as *late-life cognitive de-differentiation* (Balinsky, 1941), has recently become an important concept in the field of life span cognition. Several hypotheses have recently emerged to explain cognitive de-differentiation in late life (Ghisletta & de Ribaupierre, 2005): general slowing (Salthouse, 1996), physiological and nervous system functioning decline (Lindenberger & Baltes, 1994), increased bihemispheric (rather than unilateral) activation (Cabeza, 2001), deficient neuromodulation (Li, 2002) due to a decrease in dopamine receptors (Volkow et al., 1998) and other catecholamines (Li & Lindenberger, 1999) and decline in specific functions (Park et al., 2002). The de-differentiation hypothesis has mostly been evaluated empirically by examining the cognitive variance/covariance space, either latent or manifest, and comparing it between younger and older age groups. This approach lead to substantial evidence indicating larger correlations between cognitive functions in older than in younger adults (e.g., Balinsky, 1941; Baltes & Lindenberger, 1997; Ghisletta & Lindenberger, 2003; Hofer & Sliwinski, 2001; Li & Schmiedek, 2002; Li et al., 2004). Future work addressing the issue of the unity or diversity of executive functions should therefore take into consideration the prominent role that the mechanism of *late-life cognitive de-differentiation* may have in the generation of different patterns of correlation between younger and older adults.

To conclude, though preliminary, the present results provide evidence that switching abilities may contribute to performance of older adults in the WCST. In the literature, the WCST has been often conceptualized as a set switching task, but this idea has been independently tested only recently by Miyake et al. (2000) in a sample of university students. Given the complexity of the WCST, there are many ways to pass (or fail) this test, and so one might

[5]The task impurity problem refers to the possibility that a large proportion of the variance associated with an executive task may reflect individual variations in other idiosyncratic requirements of that task, with only a small proportion of the variance actually capturing variation in the executive processes that the task is believed to measure.

expect multiple processes, strategies and brain areas to be involved in performance of cognitively diverse samples. Therefore, Miyake et al.'s (2000) results could not be generalized to older adults. Furthermore, Miyake et al. did not differentiate between local and general switch costs components that have been shown to reflect different control processes. The novel contribution of the present study is therefore that it identifies the local switch component as the primary process necessary to complete the WCST, at least in older adults.

One important question that needs to be considered in future research is whether task setting reconfiguration processes (e.g., Rogers & Monsell, 1995) or proactive interference processes (e.g., Allport & Wylie, 1999), which are assumed by different authors to be at the root of local switch costs, relate to performance in the WCST. Furthermore, given that age effects on switching abilities still remain an ongoing debate in the literature, further research is also needed to generalize the present results to different task-switch paradigms.

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REFERENCES

Allport, A., & Wylie, G. (1999). Task-switching: Positive and negative priming of task- set. In G. W. Humphreys, J. Duncan & A. M. Treisman (Eds), *Attention, space and action: Studies in cognitive neuroscience* (pp. 273–296). Oxford: Oxford University Press.

Anderson, S. W., Damasio, H., Jones, R. D., & Tranel, D. (1991). Wisconsin Card Sorting Test performance as a measure of frontal lobe damage. *Journal of Clinical and Experimental Neuropsychology*, *13*, 909–922.

Balinsky, B. (1941). An analysis of the mental factors of various age groups from nine to sixty. *Genetic Psychology Monographs*, *23*, 191–234.

Baltes, P. B., & Lindenberger, U. (1997). Emergence of a powerful connection between sensory and cognitive functions across the adult life span: A new window to the study of cognitive aging? *Psychology and Aging*, *12*, 12–21.

Band, G. P. H., van der Molen, M. W., & Logan, D. L. (2003). Horse-race model simulations of the Stop Signal procedure. *Acta Psychologica*, *112*, 105–142.

Berg, E. A. (1948). A simple objective technique for measuring flexibility in thinking. *Journal of Genetic Psychology*, *39*, 15–22.

Bedard, A. C., 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.

Bjork, R. A. (1989). Retrieval inhibition as an adaptive mechanism in human memory. In H. L. Roediger III & F. I. M. Craik (Eds), *Varieties of memory and consciousness: Essays in honour of Endel Tulving* (pp. 309–330). Hillsdale, NJ: Lawrence Erlbaum.

Bojko, A., Kramer, A. F., & Peterson, M. S. (2004). Age equivalence in switch costs for prosaccade and antisaccade tasks. *Psychology and Aging 19*, 226–234.

Borella, E., Carretti, B., & Mammarella, I. C. (2006). Do working memory and control from proactive interference predict age differences in fluid intelligence? *European Journal of Cognitive Psychology*, *18*, 51–69.

Borella, E., Carretti, B., & De Beni, R. (2008). Working memory and inhibition across the adult life span. *Acta Psychologica*, *128*(1), *33*–44.

Braver, T. S., Reynolds, J. R., Donaldson, D. I. (2003). Neural mechanisms of transient and sustained cognitive control during task-switching. *Neuron*, *39*, 713–726.

Cabeza, R. (2001). Cognitive neuroscience of aging: Contributions of functional neuroimaging. *Scandinavian Journal of Psychology*, *42*, 277–286.

Cepeda, N. J., Kramer, A. F., & Gonzalez de Sather, J. C. M. (2001). Changes in executive control across the life span: Examination of task-switching performance. *Developmental Psychology*, *37*, 715–730.

Collette, F., Van der Linden, M., Laureys, S., Delfiore, G., Degueldre, C., Luxen, A., & Salmon, E. (2005). Exploring the unity and diversity of the neural substrates of executive functioning. *Human Brain Mapping*, *25*, 409–423.

Conway, A. R. A., & Engle, R. W. (1996). Individual differences in working memory capacity: More evidence for a general capacity theory. *Memory*, *4*, 577–590.

Corcoran, R., & Upton, D. (1993). A role for the hippocampus in card sorting? *Cortex*, *29*, 293–304.

Crone, E. A., Wendelken, C., Donohue, S. E., & Bunge, S. A., (2005). Neural evidence for dissociable components of task-switching. *Cerebral Cortex*, *16*, 475–486.

Dagenbach, D., & Carr, T. H. (1994). *Inhibitory processes in attention, memory and language*. San Diego, CA: Academic Press.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior*, *19*, 450–466.

De Beni, R., & Palladino, P. (2004). Decline in working memory updating through ageing: Intrusion error analyses. *Memory*, *12*(1), 75–89.

De Jong, R. (2001). Adult age differences in goal activation and goal maintenance. *European Journal of Cognitive Psychology*, *13*, 71–89.

Delis, D. C., Kaplan, E., & Kramer, J. H. (2001). *The Delis-Kaplan Executive Function System*. San Antonio, TX: The Psychological Corporation.

Dove, A., Pollmann, S., Schubert, T., Wiggins, C. J., & von Cramon, D. Y. (2000). Prefrontal cortex a activation in task switching: An event-related fMRI study. *Cognitive Brain Research*, *9*, 103–109.

Drewe, E. A. (1974). The effect of type and area of brain lesion on Wisconsin Card Sorting Test performance. *Cortex*, *10*, 159–179.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception and Psychophysics*, *16*, 143–149.

Everling, S., & Fischer, B. (1998). The antisaccade: A review of basic research and clinical studies. *Neuropsychologia*, *36*, 885–899.

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.

Friedman, N. P., & Miyake, A. (2004). The reading span test and its predictive power for reading comprehension ability. *Journal of Memory and Language*, *51*, 136–158.

Fristoe, N. M., Salthouse, T. A., & Woodard, J. L. (1997). Examination of age-related deficits on the Wisconsin Card Sorting Test. *Neuropsychology*, *11*, 428–436.

Gamboz, N., & Russo, R. (2002). Evidence for age-related equivalence in the directed forgetting paradigm. *Brain and Cognition*, *48*, 366–371.

Gamboz, N., Russo, R., & Fox, E. (2002). Age differences and the negative priming effect: An updated meta-analysis. *Psychology and Aging*, *17*, 525–531.

Gerard, L., Zacks, R. T., Hasher, L., & Radvansky, G. A. (1991). Age deficit in retrieval: The fan effect. *Journal of Gerontology: Psychological Sciences*, *46*, 131–136.

Ghisletta, P., & Lindenberger, U. (2003). Age-based structural dynamics between perceptual speed and knowledge in the Berlin aging study: Direct evidence for ability dedifferentiation in old age. *Psychology and Aging*, *18*, 696–713.
Ghisletta, P., & de Ribaupierre, A. (2005). A dynamic investigation of cognitive dedifferentiation with control for retest: Evidence from the Swiss Interdisciplinary Longitudinal Study on the oldest old. *Psychology and Aging*, *20*, 671–682.
Grafman, J., Jonas, B., & Salazar, A. (1990). Wisconsin Card Sorting Test performance based on location and size of neuroanatomical lesion in Vietnam veterans with penetrating head injury. *Perceptual and Motor Skills*, *71*, 1120–1122.
Hamm, V. P., & Hasher, L. (1992). Age and the availability of inferences. *Psychology and Aging*, 7, 56–64.
Hartley, A. A. (1992). Attention. In F. I. M. Craik & T. A. Salthouse (Eds), *The handbook of aging and cognition*. Hillsdale, NJ: Erlbaum.
Hartman, M., Bolton, E., & Fehnel, S. E. (2001). Accounting for age differences on the Wisconsin Card Sorting Test: Decreased working memory, not inflexibility. *Psychology and Aging*, *16*, 385–399.
Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 22, pp. 193–225). San Diego, CA: Academic Press.
Heaton, R. A. (1981). *Manual for the Wisconsin Card Sorting Test*. Odessa, FL: Psychological Assessment Resources.
Heaton, R. K., Chelune, G. J., Talley, J. L., Kay, G., & Curtiss, G. (1993). *Wisconsin Card Sorting Test manual: Revised and expanded*. Odessa, FL: Psychological Assessment Resources.
Hedden, T., & Yoon, C. (2006). Individual differences in executive processing predict susceptibility to interference in verbal working memory. *Neuropsychology*, *20*, 511–528.
Hofer, S. M., & Sliwinski, M. J. (2001). Understanding aging. *Gerontology*, *47*, 341– 352.
Kane, M. J., & Engle, R. W. (2002). The role of prefrontal cortex in working memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective. *Psychonomic Bulletin and Review*, *9*, 637–671.
Kimberg, D., & Farah, M. J. (1993). A unified account of cognitive impairment following frontal lobe damage: The role of working memory in complex, organized behavior. *Journal of Experimental Psychology: General*, *122*, 411– 428.
Koch, I., Prinz, W., & Allport, A. (2005). Involuntary retrieval in alphabet-arithmetic tasks: Task-mixing and task-switching costs. *Psychological Research*, *69*, 252–261.
Kok, A. (1999). Varieties of inhibition: Manifestations in cognition, event-related potentials and aging. *Acta Psychologica*, *101*, 129–158.
Konishi, S., Nakajima, K., Uchida, I., Kikyo, H., Kameyama, M., & Miyashita, Y. (1999). Common inhibitory mechanism in human inferior prefrontal cortex revealed by event-related functional MRI. *Brain*, *122*, 981–991.
Kramer, A. F., Humphrey, D. G., Larish, J. F., Logan, G. D., & Strayer, D. L. (1994). Aging and inhibition: Beyond a unitary view of inhibitory processes in attention. *Psychology and Aging*, *4*, 491–512.
Kray, J. (2006). Task-set switching under cue-based versus memory-based switching conditions in younger and older adults. *Brain Research*, *1105*, 83–92.
Kray, J., & Lindenberger, U. (2000). Adult age differences in task-switching. *Psychology and Aging*, *15*, 126–147.
Kray, J., Li, K. Z. H., & Lindenberger, U. (2002). Age-related changes in task- switching components: The role of task uncertainty. *Brain and Cognition 49*, 363–381.
Li, S. C. (2002). Connecting the many levels and facets of cognitive aging. *Current Directions in Psychological Sciences*, *11*, 38–43.

Li, S. C., & Lindenberger, U. (1999). Cross-level unification: A computational exploration of the link between deterioration of neurotransmitter systems and dedifferentiation of cognitive abilities in old age. In L. G. Nilsson & H. Markowitsch (Eds), *Cognitive neuroscience of memory* (pp. 103–146). Toronto: Hogrefe & Huber.
Li, S. C., & Schmiedek, F. (2002). Aged is not aging: Understanding the clocks that time the aging mind. *Gerontology*, *48*, 5–12.
Li, S. C., Lindenberger, U., Hommel, B., Aschersleben, G., Prinz, W., & Baltes, P. B. (2004). Lifespan transformations in the couplings of mental abilities and underlying cognitive processes. *Psychological Science*, *15*, 155–163.
Li, K. Z. H., Hasher, L., Jonas, D., May, C. P., & Rahhal, T A. (1998). Distractibility, circadian arousal, and aging: A boundary condition ? *Psychology and Aging*, *13*, 574–583.
Lindenberger, U., & Baltes, P. B. (1994). Sensory functioning and intelligence in old age: A strong connection. *Psychology and Aging*, *9*, 339–355.
Logan, G. D. (1994). On the ability to inhibit thought and action: A user's guide to the stop signal paradigm. In D. Dagenbach & T. H. Carr (Eds), *Inhibitory processes in attention, memory, and language* (pp. 189–239). San Diego, CA: Academic Press.
Logan, G. D., Schachar, R. J., & Tannock, R. (1997). Impulsivity and inhibitory control. *Psychological Science*, *8*, 60–64.
Los, S. A. (1996). On the origin of mixing costs: Exploring information processing in pure and mixed blocks of trials. *Acta Psychologica*, *94*, 145–188.
MacLeod, C. M., Dodd, M. D., Sheard, E. D., Wilson, D. E., & Bibi, U. (2003). In opposition to inhibition. In B.H. Ross (Ed.), *The psychology of learning and motivation* (Vol. 43, pp. 163–214). New York: Elsevier Science.
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.
Mayr, U., & Kliegl, R. (2000). Complex semantic processing in old age: Does it stay or does it go? *Psychology and Aging*, *15*, 29–43.
Mayr, U., & Liebscher, T. (2001). Is there an age deficit in the selection of mental sets? *European Journal of Cognitive Psychology*, *13*, 47–69.
McCabe, J., & Hartman, M. (2003). Examining the locus of age effects on complex span tasks. *Psychology and Aging*, *18*, 562–572.
Meiran, N. (1996). Reconfiguration of processing mode prior to task performance. *Journal of Experimental Psychology*, *22*, 1423–1442.
Meiran, N. (2000). Reconfiguration of the stimulus task-set and the response task-set during task switching. In S. Monsell, & J. Driver (Eds), *Attention & performance XVIII: Control of cognitive processes* (pp. 377–400). Cambridge, MA: MIT Press.
Meiran, N., Gotler, A., & Perlman, A. (2001). Old age is associated with a pattern of relatively intact and relatively impaired task-set switching abilities. *Journal of Gerontology: Psychological Sciences*, *56*, 88–102.
Milliken, B., Joordens, S., Merikle, P. M., & Seiffert, A. E. (1998). Selective attention: A reevaluation of the implications of negative priming. *Psychological Review*, *105*, 203–229.
Milner, B. (1963). Effects of different brain lesions on card sorting. *Archives of Neurology*, *9*, 90–100.
Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (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.
Mountain, M. A., & Snow, W. G. (1993). Wisconsin Card Sorting Test as a measure of frontal pathology: A review. *The Clinical Neuropsychologist*, *7*, 108–118.
Nagahama, Y., Fukuyama, H., Yamauchi, H., Matsuzaki, S., Konishi, J., Shibasaki, H., Kimura, J. (1996). Cerebral activation during performance of a card sorting test. *Brain*, *119*, 1667–1675.

Nelson, H. E. (1976). A modified card sorting test sensitive to frontal lobe defects. *Cortex, 12*, 313–324.

Park, D. C., Lautenschlager, G., Hedden, T., Davidson, N. S., Smith, A. D., & Smith, P. K. (2002). Models of visuospatial and verbal memory across the adult life span. *Psychology and Aging*, *17*, 299–320.

Pazzaglia, F., Palladino, P., & De Beni, R., (2000). Presentazione di uno strumento per la valutazione della memoria di lavoro verbale e sua relazione con i disturbi della comprensione. *Psicologia Clinica dello Sviluppo*, *3*, 465–486.

Rabbitt, P. (1997). Introduction: Methodologies and models in the study of executive functions. In P. Rabbitt (Ed.), *Methodology of frontal and executive function* (pp. 1–38). Hove, UK: Psychology Press.

Rabbitt, P., Lowe, C., & Shilling, V. (2001). Frontal tests and models for cognitive ageing. *European Journal of Cognitive Psychology, 13,* 5–28.

Raven, J. C., Court, J. H., & Raven, J. (1995). *Coloured progressive matrices*. Oxford: Oxford Psychologists Press.

Raz, N. (2000). Aging of the brain and its impact on cognitive performance: Integration of structural and functional findings. In F. I. M. Craik & T. A. Salthouse (Eds), *The handbook of aging and cognition* (2nd. ed.). Mahwah, NJ: Lawrence Erlbaum Associates.

Reitan, R. M., & Wolfson, D. (1994). A selective and critical review of neuropsychological deficits and the frontal lobes. *Neuropsychology Review*, *4*, 161–197.

Rhodes, M. G. (2004). Age-related differences in performance on the Wisconsin Card Sorting Test: A meta-analytic review. *Psychology and Aging*, *19,* 482–494.

Ridderinkhof, K. R., Band, G. P. H., & Logan, G. D. (1999). A study of adaptive behavior: Effects of age and irrelevant information on the ability to inhibit one's actions. *Acta Psychologica*, *101*, 315–337.

Rogers, R. D., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General*, *124*, 207–231.

Rubin, O., & Meiran, N. (2005). On the origins of the task mixing cost in the cuing task-switching paradigm. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *31*, 1477–1491.

Ruthruff, E., Remington, R. W., & Johnston, J. (2001). Switching between simple cognitive tasks: The interaction of top-down and bottom-up factors. *Journal of Experimental Psychology: Human Perception and Performance*, *27*, 1404–1419.

Sahakyan, L., & Delaney, P. F. (2003). Can encoding differences explain the benefits of directed forgetting in the list method paradigm? *Journal of Memory and Language*, *48*, 195–206.

Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review*, *103*, 403–428.

Salthouse, T. A., Fristoe, N., & Rhee, S. H. (1996). How localized are age-related effects on neuropsychological measures ? *Neuropsychology*, *10*, 272–285.

Salthouse, T. A., Fristoe, N. M., McGuthry, K. E., & Hambrick, D. Z. (1998). Relation of task switching to speed, age, and fluid intelligence. *Psychology and Aging 13*, 445–461.

Sego, S. A., Golding, J. M., & Gottlob, L. R. (2006). Directed forgetting in older adults using the item and list methods. *Aging, Neuropsychology, and Cognition*, *13,* 95–114.

Stuss, D. T., & Alexander, M. P. (2000). Executive functions and the frontal lobes: A conceptual view. *Psychological Research*, *63*, 289–298.

Stuss, D. T., Alexander, M. P., & Benson, D. F. (1997). Frontal lobe functions. In M. R. Trimble & J. L. Cummings (Eds), *Contemporary behavioral neurology* (pp. 169–187). Boston, MA: Butterworth-Heineman.

Tipper, S. P. (2001). Does negative priming reflect inhibitory mechanisms? A review and integration of conflicting views. *Quarterly Journal of Experimental Psychology*, *54*, 321–343.

Tisserand, D. J., & Jolles, J. (2003). On the involvement of prefrontal networks in cognitive aging. *Cortex*, *39*, 1107–1128.

van Asselen, M., & Ridderinkhof, K. R. (2000). Shift costs of predictable and unexpected set shifting in young and older adults. *Psychologica Belgica*, *40*, 259–273.

Vanderploeg, R. D., Schinka, J. A., & Retzlaff, P. (1994). Relationship between measures of auditory verbal learning and executive functioning. *Journal of Clinical and Experimental Neuropsychology*, *16*, 243–252.

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

Verhaeghen, P., Marcoen, A., & Goossens, L. (1993). Facts and fiction about memory and aging: A quantitative integration of research findings. *Journal of Gerontology: Psychological Sciences*, *48*, 157–171.

Volkow, N. D., Gur, R. C., Wang, G., Fowler, J. S., Moberg, P. J., Ding, Y., et al. (1998). Association between decline in brain dopamine activity with age and cognitive and motor impairment in healthy individuals. *American Journal of Psychiatry*, *155*, 344–349.

Wager, T. D., & Smith, E. E. (2003). Neuroimaging studies of working memory: A meta-analysis. *Cognitive and Affective Behavioral Neuroscience*, *3*, 255–274.

West, R. L. (2000). In defense of the frontal lobe hypothesis of cognitive aging. *Journal of the International Neuropsychological Society*, *6*, 727–729.

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

Zacks, R. T., & Hasher, L. (1994). Directed ignoring: Inhibitory regulation of working memory. In D. Dagenbach & T. H. Carr (Eds), *Inhibitory processes in attention, memory and language* (pp. 241–264). San Diego, CA: Academic Press.

Zelazo, P. D., Craik, F. I. M., & Booth, L. (2004). Executive function across the life span. *Acta Psychologica*, *115*, 167–184.

Zellner, M., & Bäuml, K. H. (2006). Inhibitory deficits in older adults. List-method directed forgetting revisited. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *32*, 290–300.