ARTICLE IN PRESS

Brain and Cognition xxx (2012) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Brain and Cognition

journal homepage: www.elsevier.com/locate/b&c

A latent variable approach to executive control in healthy ageing

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ARTICLE INFO

Article history:
Accepted 9 January 2012
Available online xxxx

Keywords:
Structural equation modeling
Dedifferentiation
Speed
Verbal fluency

ABSTRACT

It is a well-established finding that the central executive is fractionated in at least three separable component processes: Updating, Shifting, and Inhibition of information (Miyake et al., 2000). However, the fractionation of the central executive among the elderly has been less well explored, and Miyake's et al. latent structure has not yet been integrated with other models that propose additional components, such as access to long-term information. Here we administered a battery of classic and newer neuropsychological tests of executive functions to 122 healthy individuals aged between 48 and 91 years. The test scores were subjected to a latent variable analysis (LISREL), and yielded four factors. The factor structure obtained was broadly consistent with Miyake et al.'s three-factor model. However, an additional factor, which was labeled 'efficiency of access to long-term memory', and a mediator factor ('speed of processing') were apparent in our structural equation analysis. Furthermore, the best model that described executive functioning in our sample of healthy elderly adults included a two-factor solution, thus indicating a possible mechanism of dedifferentiation, which involves larger correlations and interdependence of latent variables as a consequence of cognitive ageing. These results are discussed in the light of current models of prefrontal cortex functioning.

1. Introduction

Successful ageing has been related to high executive functioning and to a largely preserved prefrontal function (West, 1996). Thus, a growing body of research evidence points to an age-related deficit in central executive functioning (Moscovitch & Winocur, 1995; West, 1996). Such deficits have been documented by using a range of prefrontal neuropsychological tasks that are believed to tap executive processes, such as the WCST and the Stroop test (Mittenberg, Seidenberg, O'Leary, & DiGiulio, 1989). Miyake et al. (2000) showed that executive functions can be subdivided into three separate types of operations: Shifting, Updating, and Inhibition of information. 'Shifting' concerns the ability to switch attention between different sub-tasks or different elements of the same task. The 'Updating' component involves evaluating incoming information and revising the existing contents of working memory as necessary by deleting what is no longer relevant and incorporating more recent information. Lastly, 'Inhibition' refers to the individual's ability to withhold automatic or prepotent responses. While these three operations may share some common element, Miyake et al. (2000) showed that they are separable, with different executive tasks loading heavily on just one or two specific operations. Thus, we aimed both at applying Miyake's model to study age-related cognitive decline while further addressing the role of processing speed, long-term memory access, and to establish the degree of dedifferentiation of executive functioning in healthy elderly adults.

In support of this claims, we have shown using event-related potentials (ERPs) in both healthy young (Barceló, Escera, Corral, & Perianez, 2006), elderly (Adrover-Roig & Barceló, 2010), and patients with prefrontal lesions (Barceló & Knight, 2007), that there exists a neat anatomical and functional dissociation between Shifting and Updating of information, with the former related to novel higher-level task-set representations and the latter related to familiar and lower-level task-set representations. Moreover, in these studies, we pointed to a hierarchical information processing of novel versus familiar information as a critical determinant of contextual shifting or updating, with more familiar and frequently updated information involving Updating, but more infrequently updated and newer stimulation largely involving Shifting. This functional distinction also seems to correspond with an anatomical counterpart in that only Shifting seems to activate the prefrontal cortex, whereas Updating may be implemented at posterior cortical and/or subcortical structures (Barceló & Knight, 2007; Knight, 1984). In line with the long-lasting problems of construct validity, neurophysiological evidence suggests that the three basic executive functions, Shifting, Updating, and Inhibition, may be better described within a hierarchy of cognitive representations (Koechlin & Summerfield, 2007). However, the latter results were

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doi:10.1016/j.bandc.2012.01.005

obtained from a sample of young adults and Miyake et al. (2000) acknowledge that studies on healthy elderly populations (Hull, Martin, Beier, & Lane, 2008) have reported a lesser number of latent factors than those reported by Miyake et al. (2000), but Huizinga, Dolan, and van der Molen (2006) explored changes in executive functioning in 8–13 year old children, and provided some support for Miyake et al.'s factor structure. Nevertheless, the category of functions described as 'executive' is abstract and composed of diverse elements, and, as such, measures of executive functioning vary considerably in their design and in the strength of their relationships with one another (Salthouse, Atkinson, & Berish, 2003).

First, regarding Shifting, the so-called task-switching paradigms have been frequently used in the study of normal age-related differences in cognitive control (Adrover-Roig & Barceló, 2010; Kray, Li, & Lindenberger, 2002). Specifically, component processes underlying task switching have been proposed to allow the segregation of different executive components and the study of their interactions (Meiran, 1996; Rogers & Monsell, 1995). Thus, executive control during task-switching refers to: (a) the change of task-set configurations, and (b) the selection of higher level goals or task sets and the maintenance of task representations (see Mayr, 2001). In most of the recent work, the first task-switching component has been defined as the difference between performance on responses in which a task switch occurs and those in which a task is repeated within blocks of trials (henceforth called local switch costs; Rogers & Monsell, 1995). These local switch costs are assumed to represent how well the cognitive system establishes new stimulus–response rules; that is, how well it activates currently relevant stimulus–response rules and deactivates previously relevant ones. The bulk of studies have not yet decided what are the fundamental differences constraining age-related differences in the ability to switch flexibly between cognitive sets (Kray et al., 2002). Other studies have rather pointed out to the age-related maintenance deficit during task switching (Adrover-Roig & Barceló, 2010; West & Travers, 2008). However, although Miyake et al. maintain that the WCST task is primarily dependent on the Shifting component, other researchers (e.g., Wang, Kakigi, & Hoshiyama, 2001) have maintained that it also involves inhibitory processes (i.e., when a category shift occurs the former response has to be inhibited) and an updating component (each time the category changes working memory has to be updated). Thus, relative to Miyake et al.'s findings, it is possible that fewer factors may emerge or that there will be a predominance of complex factor loadings.

Secondly, an age-related deficit in the updating of information has been linked to an impaired capacity that involves a difficulty in internally representing context for cognitive and behavioral control (Braver & Barch, 2002; Braver et al., 2001). Finally, previous reports have highlighted the impact of age on the inhibitory capacity, as expressed by Hasher, Stoltzfus, Zacks, and Rypma (1991). Their proposals have received extensive support from different studies employing several paradigms, which have reported a slower and more error prone performance in elderly subjects when dealing with incongruent trials in Stroop tasks (Houx, Jolles, & Vreeling, 1993). Interestingly, Hasher, Zacks, and Rahhal (1999) closely related the age-related deficit in inhibitory control with a general deficit in with working memory capacity, as the authors reported conflicting information to be mainly related working memory contents (Hasher et al., 1999). However, not all tasks of inhibitory control demand a large implication of prefrontal cortices (Nigg, 2000), as some tasks involve automatic, non-intentional inhibitory processing (Collette & van der Linden, 2002), in part because these are partly segregable (Kramer, Humphrey, Larish, Logan, & Strayer, 1994). Hence, if Miyake et al.'s segregation of executive processes does indeed apply to individual differences over the adult age span, it would be of interest to establish the extent to which each of the three separable processes are subject to age-related decline. All in all, the impact of the three separable components of executive control in cognitive ageing could be framed in the unifying theory of age-related cognitive decline so-called 'frontal ageing hypothesis' (West, 1996). While sharing the advantage of a parsimonious explanation of age-related cognitive deficits, it is of importance to note that the proposed model proposed by Braver and Barch (2002) makes the explicit assumption that age-related cognitive deficits pertain to the loss of PFC function in the representation, maintenance and updating of contextual information (see also West & Moore, 2005).

1.1. Dedifferentiation of executive functions (EF) in elderly adults

The exploration of EF in the elderly has showed that measures representing the Shifting and Inhibition latent variables might yield a single-factor model that can fit the data well, which is invariant across gender and age groups (young–old, and old–old) (De Frias, Dixon, & Strauss, 2006). This has left open the interpretation that a process labeled as 'dedifferentiation' (from multidimensional to unidimensional representations or constructs) of EF may have occurred over the adult life span, or that specific ageing-related population groups may produce different solutions. Thus, a differentiated factor structure to that described in healthy younger adults may be observed to the extent that neurodegenerative processes occur differentially across brain structures and across ageing individuals. In this regard, Hedden and Yoon (2006) administered to 122 healthy older adults aged 63–82 a battery of tests measuring executive function, memory, and perceptual speed, and employed structural equation modeling to investigate the relationships of these constructs with susceptibility to interference in a working memory task. Their results showed that executive function was best described as two related subcomponent processes that involved Shifting and Updating of information in the same latent variable, and the Inhibition of Proactive Interference as the second latent variable. Importantly, these subcomponents were distinct from verbal and visual memory and Speed. Of note is that the authors could not distinguish a separate construct of Inhibition of prepotent responses from Speed, as it was the case in Miyake et al. (2000). Thus, it appears that the Inhibition construct is not easily distinguishable among healthy elderly adults. The authors further highlighted that the capacity to shift, to update, or refresh, representations of task contexts, along with the ability to suppress competing representations, are indicators of the susceptibility to interference in working memory. This supported the idea that executive control of attention plays a decisive role in the maintenance of internal representations and keeps them from being distorted by interference. In light of these claims, it seems that resistance of interference and the maintenance of internal representations in working memory are closely related, but different from a Shifting construct and a construct representing Speed.

Conceivably, adaptive features or mechanisms (such as cognitive reserve and compensation) associated to dedifferentiation may prolong the onset of normative neurological decline (or permit cognitive manifestations consistent with this assumption). This could maintain differentiated structures and perhaps higher levels of performance, thereby delaying dedifferentiation of EFs (e.g., Buckner, 2004; Reuter-Lorenz & Cappell, 2008; Stern, 2006). Cognitive reserve (CR) postulates that individual differences in the cognitive processes or neural networks underlying task performance allow some people to cope better than others with brain damage, and this might be the result of accumulated life experiences (such as years of formal education, occupational status, leisure habits, physical activity, or even bilingualism and multilingualism). The presence of some of these factors is associated with reduced risk of developing dementia, and also with a slower rate of memory decline with advancing age (see Stern, 2009, for a review). Interestingly, it is the combination of factors what appears to decrease the risk of developing dementia, and not the mere classification of participants according to one environmental factor (Scarmeas, Levy, Tang, Manly, & Stern, 2001). Further, a comprehensive review of cohort studies that looked at the effect of education, occupation, premorbid IQ, and mental activities in incident dementia estimated a decrease in risk of 46% in individuals with high measures in CR (Valenzuela & Sachdev, 2005). All these studies point out the importance of CR on cognitive ageing, and as such, it would be reasonable to expect CR to have an impact on the multifaceted nature of executive functioning among healthy elderly participants. Thus, the general guiding principle following a dedifferentiation mechanism is that a more differentiated structure of EF would be observed for a more cognitively intact group (in De Frias et al. (2006) labeled as 'cognitive elite', (CE), consistent with the notion that their executive functioning may resemble that of younger adults, as compared to cognitively normal (CN) older adults. Thus, the dedifferentiation hypothesis (Antsey, Hofer, & Luszcz, 2003) posits that the distinction among cognitive abilities blurs with age and is reflected in significantly increased correlations between factors, or even reduction to a single factor. Salthouse and colleagues (Salthouse et al., 2003; see also Salthouse, 2001) have argued in favor of the dedifferentiation hypothesis based on their observations that performance by adults aged 18–84 years on a variety of cognitive tasks more strongly related to fluid intelligence scores than to the executive function constructs of for example, Inhibition. Furthermore, Ghisletta and Lindenberger (2003) reported dedifferentiation effects for perceptual speed, and weak effects for semantic knowledge in adults aged 70–103 years ($N = 516$). In contrast, a separate study using the same age range ($N = 1.823$) reported no evidence for dedifferentiation (Antsey et al., 2003) in high-ability individuals, and only inconsistent evidence in low-ability individuals (see also West & Schwarb, 2006). These outcomes suggest that cognitive ability may be a better predictor of age-related cognitive change than chronological age (Antsey et al., 2003).

1.2. The role of information processing speed

Information processing speed has been proposed as a modulator of executive capacity among the elderly (Salthouse, 1996; Salthouse, Fristoe, McGuthry, & Hambrick, 1998), and it has been claimed to underpin many of the age-related cognitive deficits that have been demonstrated in previous research. For example, Salthouse, Babcock, and Shaw (1991) have shown that age-related deficits in reading and computation span are reduced to below statistical significance following control for age differences in processing speed. Moreover, processing speed has been shown to have a similar attenuating effect in relation to age differences in random letter generation (Fisk & Warr, 1996) and WCST performance (Fristoe, Salthouse, & Woodard, 1997). However, the role of processing speed in attenuating age differences during task switching and verbal fluency (access) is less clear. Nonetheless, the general slowing theory of cognitive ageing is very influential (Salthouse, 1996; Verhaeghen & Salthouse, 1997) and given that Miyake et al.'s separable executive components are valid for an age heterogeneous group, it would clearly be of interest to investigate the role of processing speed in mediating any age-related variance in these components. In this regard, Salthouse (1996) proposed a processing speed theory that explained the apparent multiplicity of age-related cognitive deficits to a general decrease in the speed with which cognitive/neural operations can be executed. Therefore, Salthouse (1996) reanalyzed their own data with structural equation models (SEMs) to examine the relations among age, speed, shifting, and measures of cognitive performance. Two models were considered that were structurally identical except that in one case a path was specified from the switching measure to the speed construct, and in the other case the direction of this path was reversed. Both models had the same fit to the data. However, two of the relations among age, speed, and the switching measure were stronger when the path was from the speed construct to the switching construct instead of from the switching construct to the speed one. Further examination of their results revealed that statistical control of speed reduced the age–switch relation by 64% (from .53 to .19), whereas statistical control of the switching measure reduced the age–speed relation by only 22% (i.e., −.73 to −.57). The authors considered that a possible implication of these results was that perceptual speed could be more fundamental with respect to relations between age and cognition than a construct related to switching. Given that Salthouse and colleagues have reported strong correlations between measures of executive functioning, abstract reasoning and perceptual speed (Salthouse, 2005; Salthouse et al., 2003) the role of processing speed in attenuating age differences in task switching performance, word fluency, and Semantic fluency was a major aim in the prior study. Speed of processing is also important because specific training on speed leads to improved cognitive function and daily living activities. In this regard, Ball, Edwards, and Ross (2007) administered several types of cognitive training to a large set of participants, who were randomly assigned one of four groups. One group received 10-session group training for memory (verbal episodic memory; $n = 711$), another group received training for reasoning (ability to solve problems that follow a serial pattern; $n = 705$), and a third group was trained in speed of processing (visual search and identification; $n = 712$). A control group ($n = 704$) was also included. Eleven months after training, 4-session booster training was offered to a 60% random sample. Their results showed that each specific cognitive ability improved with each intervention, and this was even durable to 2 years. Notably, Speed training was the intervention that improved more after intervention (87% Speed, 74% Reasoning, 26% Memory) and also the training intervention that benefited more from booster training. Another relevant study by Ball et al. (2007) combined data from six studies that had employed the same speed of processing training program in order to evaluate training gains on cognitive and everyday abilities of elderly adults, and found that those adults with initial speed of processing deficits improved the most among all participants, and that benefits were maintained for at least two years and were also evident in everyday living activities. Importantly, they showed that training gains were related to baseline speed of processing and psychomotor speed measures, but not to visual sensory or visual memory and only weakly related to executive function measures. The authors further discuss that processing speed measures require executive functioning. Later on, Smith et al. (2009) administered an extensive training program to 242 healthy elderly participants, which consisted of six computerized exercises designed to improve the speed and accuracy of auditory information processing, by means of reward and animation. The exercises were constrained to improve the acoustic organization of speech, and included several subtasks, such as time order judgment of pairs of frequency-modulated sweeps, discrimination of confusable syllables, recognition of sequences of confusable syllables, matching pairs of confusable syllables, reconstruction of sequences of verbal instructions, and identification of details in a verbally presented story. Of note is that auditory stimuli were processed to exaggerate the rapid temporal transitions within the sounds by increasing their amplitude and stretching them in time so as to increase the effectiveness by which stimuli engage and drive plastic changes in brain systems, and this exaggeration was gradually removed over the course of the training period. Results of this interesting work showed that

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a cognitive training program designed to improve both the speed and the accuracy of central auditory system can drive benefits that generalize to untrained measures of memory and attention and that the improvement was larger than that seen with a program of general cognitive stimulation.

1.3. The role of long-term memory access

Tasks demanding the access to long-term verbal and Semantic fluency contents have been demonstrated to constitute a different executive component, beyond Shifting, Updating, and inhibition (Fisk & Sharp, 2004). Fisk and Sharp (2004), using an oblique rotation method, obtained a four-factor structure that was broadly consistent with Miyake et al.'s. However, an additional factor, the only one not to show a significant performance decline with age, was also obtained and was believed to reflect the efficiency of access to long-term memory. Thus, a more integrated view of this component into Miyake's and Salthouse's models may be needed. In this regard, Baddeley and Della Sala (1996) noted that one of the key functions of the executive is the temporary activation of long-term memory, which can be assessed through word fluency testing. It would appear that word fluency involves this aspect of executive functioning, since participants are required to retrieve as many words as they can from long-term memory.

Consistent with this viewpoint, Ruff, Light, Parker, and Levin (1997) reported that word fluency performance was significantly correlated with long-term but not short-term recall. Thus, the inclusion of word fluency (access) measures in the present work may tap an important area of executive functioning that was not specifically addressed by Miyake et al. (2000). However, it remains unclear whether or not word fluency measures share most of their variance with the Updating, Shifting and Inhibition components, or whether they will give rise to an additional factor. While word fluency measures do not obviously map onto any of Miyake et al.'s component processes, fluency is nonetheless an established measure of executive functioning and prefrontal integrity (Parkin & Jara, 1999). For example, brain lesion studies have demonstrated that damage to the left dorsolateral prefrontal region impairs both letter-based and category-based fluency (Stuss et al., 1998). Furthermore, relative to control conditions, the left prefrontal cortex has been found to be more active during word fluency tasks (Elfgren & Risberg, 1998). Therefore, if it is accepted that the involvement of prefrontal structures is a necessary condition for defining what is an executive process, then word fluency might be considered as an executive task. Thus, we aimed to replicate Miyake's et al. (2000) latent structure by employing a broad battery of neuropsychological tasks that included the Stroop test, Trail Making Test, Madrid Card Sorting Test (MCST), CANTAB-Paired Associates Learning-PAL, and Digits Forward and Backward, some of which were included in Miyake et al.'s study, and the rest can be assumed to load on one or more of Miyake et al.'s three basic functions (see Methods section). For the reasons stated above, several other tests were incorporated, which are known to tap onto abilities specifically affected by prefrontal damage, such as verbal fluency (Controlled Oral Word Association Test-COWAT), long-term memory access (Semantic fluency and Boston Naming Test), and rule flexibility (Brixton test).

1.4. Latent variable analyses of executive functions

There are a number of problems, such as task impurity, test–retest reliability and construct validity that seriously undermine the utility of typical correlational, factor-analytic studies for theorizing about the organization of executive functions and their roles in complex cognition (Baddeley, Della Sala, Papagno, & Spinnler, 1997). These traditional methods have had considerable utility as exploratory tools, but new approaches that overcome these problems are needed for further theoretical development. One such promising approach is latent variable analysis. Following Miyake et al. (2000), we have examined the extent of unity or diversity of executive functions at the level of latent variables, rather than at the level of manifest variables or individual tasks. In other words, we statistically 'extract' what is common among the tasks selected to tap a putative executive function and use that 'purer' latent variable factor to examine how different executive functions relate to one another. The emphasis on latent variables should minimize the task impurity problem and the construct validity problem. We focused – but not restricted ourselves – to the three executive functions selected by Miyake et al. (2000): (a) shifting between task sets, (b) updating and monitoring of working memory representations, and (c) inhibition of prepotent responses. The tasks that were meant to load on one or more of Miyake et al.'s three basic functions were: Stroop test, Trail Making Test, Madrid Card Sorting Test (MCST), CANTAB-Paired Associates Learning-PAL, and Digits Forward and Backward. Their assumed loadings onto each of the three basic executive functions will be explained in the Methods section.

Moreover, we wanted to explore whether Miyake's model could be extended to encompass other indicators of executive functions that were not included in their model and that are known to be selectively impaired following frontal lobe damage and cognitive ageing (e.g., long-term memory access and rule flexibility). In consequence, several other tests were incorporated in our model (verbal fluency as measured with Controlled Oral Word Association Test-COWAT, Semantic fluency, and naming, as measured with the Boston Naming Test), and rule flexibility (Brixton test). Finally, given the contribution of speed of processing to the individual differences on cognitive ageing (Salthouse, 1996; Salthouse et al., 1998), both the Trail Making Test (part A), the Stroop Word denomination test, and the Digit Symbol test were further included in the model. This might extend Miyake's results by considering a newer variable that is known to modulate cognitive performance in ageing (Salthouse, 1996) and that was not considered in Miyake's model.

Following our rationale, the present study aimed to clarify (1) if our latent variable approach replicated or complemented (by using factor scores to extract the latent variable structure, rather employing the direct scores from the executive tasks themselves) that of Miyake et al.'s (2) if Miyake's latent variable structure holds even when employing a different set of classic, as well as newer executive tasks, and (3) if there is any age-related variance in the three main latent variables (Updating, Inhibition, and Shifting) that was not captured by Miyake's model (according to Salthouse, one likely candidate is 'speed of processing', and according to Fisk and Sharp, the access to 'long-term memory' could be another candidate). In particular, we wanted to explore whether these latent variables may be hierarchically related among them in our sample of elderly adults. Finally, the exploration of the dedifferentiation hypothesis was considered also a goal of the present study in our sample of cognitively normal elderly adults.

2. Methods

2.1. Participants

One hundred and twenty-two participants took part in the study (mean age = 62.3 years, SD = 8.4 years; range 48–91; 65% females). They all had normal or corrected-to-normal visual acuity. History of neurological disease, psychiatric illness, head injury, stroke, substance abuse (excluding nicotine), learning disabilities, or any other difficulty that could interfere with behavioral testing were criteria for exclusion. In addition, subjects with scores lower than 28 on the Mini Mental State Examination (Folstein, Folstein, & McHugh, 1975), higher than 0.5 on the Clinical Dementia Rating, (Hughes, Berg, & Danzinger, 1982) or higher than 14 points on the Geriatric Depression Scale (Yesavage et al., 1982) were discarded for the analysis. The experiments were performed in accordance with the Declaration of Helsinki, and informed consent was obtained from all subjects.

2.2. Materials and procedures

2.2.1. Neuropsychological measures of executive functions

All participants completed the tasks hypothesized to tap one of the three target executive functions of Shifting, Updating, or Inhibition (Stroop-CW, TMT-B, MCST, and Digits Forward and Backward), five complex tasks commonly used as measures of executive functioning (Rey-Osterrieth Complex Figure, COWAT, Semantic fluency, Boston, Brixton, CANTAB-PAL), and other tasks most sensitive to cognitive slowing (TMT-A, Stroop-P, Digit Symbol). Task administration was paper-and-pencil except for two computerized tasks (MCST, CANTAB-PAL). A button box with millisecond accuracy was employed for the computerized tasks using reaction time (RT) measures. Each of these tests has Spanish norms available for the range of ages of our participants.

2.2.1.1. Boston Naming Test (Kaplan, Goodglass, & Weintraub, 2001). This test assessed the naming ability of participants. The scoring of errors was based on the number of first error responses to items not named correctly before a phonemic cue. We excluded from these analyses those trials that were: (1) no responses —instances where the subject failed to say anything prior to the phonemic cue; (2) accessory commentaries such as "I forgot the name of this thing"; (3) vague or personal responses such as "I have one of those", without any description of the object; (4) negative responses such as "not a rat"; and (5) fragmented responses such as "cla-". The range between minimum and maximum scores is 0–30.

2.2.1.2. Brixton test (Burgess & Shallice, 1997). This test evaluated the participants' capacity to discover and shift logical rules. The test consisted of a series of 56 A4-sized cards that were presented one at a time. Each card had the same basic template: a 2×5 array of circles numbered 1–10, and only one of which was filled blue. The only difference between the cards was the position of the filled circle. Participants had to predict which circle would be filled on the next card before turning the page over. The correct position could be determined based on a simple rule, which changed unpredictably after between 3 and 8 pages. The complete task involved eight changes in rule and six different rules. Examples of the rules used were "filled circle moves one order down", or "filled circle alternates among positions 4 and 10". The scoring consisted of the number of errors, which ranged between 0 and 56.

2.2.1.3. CANTAB Paired Associated Learning (Robbins, Owen, Sahakian, McInnes, & Rabbitt, 1994). The PAL test assesses visual memory capacity and new learning, in which 1, 2, 3, 6 or 8 visual patterns are sequentially disclosed from behind six filled boxes around the screen (or eight boxes in the 8-pattern stage). The patterns are then shown on the middle of the screen, one at a time, and the subject must select the box where the pattern was originally located. If all the responses are correct, then the test moves onto the next stage. Any incorrect response will result in all the patterns being reallocated to their original locations, followed by another recall phase. The task terminates after 10 display and recall phases even when the patterns have not been placed correctly. This test scores the errors made by the subject, the number of trials required to locate the pattern(s) correctly, memory scores and stages completed. The administration time was around 10 min long.

2.2.1.4. Controlled Oral Word Association Test (COWAT, Benton & Hamsher, 1976). The total number of words generated in 1 min for the letters F, A, and S was obtained from all participants. The instructions were identical to those used by Spreen and Strauss (1998). Participants were instructed that proper nouns and multiple words using the same stem with a different suffix were not acceptable.

2.2.1.5. Digits Forward and Backward subtests (Weschsler, 1999). These subtests from the WAIS-III (Spanish version) were used in order to assess working memory and mental tracking processes. Both direct scores (forward and backward) we recorded separately and included in the analyses as dependent measures.

2.2.1.6. Digit Symbol subtest (Weschsler, 1999). Perceptual speed was assessed using the Digit Symbol subtest from the WAIS-III (and also through the part A of the Trail Making Test, and the Stroop Word subtest, see below). Two minutes were allowed for the participant to perform the test.

2.2.1.7. Madrid Card Sorting Test (Barceló, 2003). A validated task-switching paradigm (Barceló, 2003) inspired in the WCST (Heaton, Chelune, Talley, Kay, & Curtiss, 1993) was administered to all participants. Subjects were instructed to switch between color and shape sorting rules on the basis of a trial-by-trial task-cueing procedure. The target display consisted in a compound visual stimulus containing the four WCST key-cards on top of one target card. Under the color task, participants judged whether the color of the elements inside the target card was red, green, yellow, or blue. Under the shape task, participants judged whether the shape of the items inside of the target card was a triangle, star, cross, or a circle. A switch trial was followed by a varying number of 1–5 repetition trials. The task-switching experimental session lasted between 15 and 20 min including a 5-min training period, in which participants were introduced to task rules by on-line monitoring from the experimenter. Dependent variables were both the number of Efficient Series achieved, Perseverative and Set-Loss errors committed, and Switch Cost (reaction times after substracting 'Stay' from 'Switch' trials). This task requires attentional resources to be frequently shifted or divided or strategies to be flexibly changed according to contextual demands (Braver et al., 2001). We have recently proved the sensitivity of the MCST in task switching and context maintenance in healthy elderly adults (Adrover-Roig & Barceló, 2010).

2.2.1.8. Rey Complex Figure (Rey, 1954). Both visuospatial construction and visuospatial memory were assessed with the Rey Complex Figure Test. Scoring system was based on the copy and immediate recall (after 3 min) reproductions of the figure, assigning 0–2 points for each of the 18 structural elements of the figure. Scoring ranged from 0 to 36.

2.2.1.9. Semantic fluency. The number of animal names generated in 1 min was obtained for all participants, following instructions by Rosen and Engle (1997).

2.2.1.10. Stroop Test (Jensen & Rohwer, 1966). Participants were asked to complete the three conditions (word reading (P), color naming (C), and naming colored words (CWs) as quickly and accurately as possible. Each error was indicated by the examiner, and participants were requested to correct it before continuing. The number of correct responses produced within a fixed interval of

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45 s (Spreen & Strauss, 1998) was recorded as the dependent variable.

2.2.1.11. Trail Making Test (Reitan, 1954). Participants were administered parts A and B of the Trail Making Test (TMT), according to the guidelines described by Spreen and Strauss (1998). Upon commission of an error, subjects were requested to correct it and to continue with the test until completion. Total time for parts A and B was scored in seconds, corresponding to the direct scores for TMT-A and TMT-B, respectively. Additionally, we obtained two derived scores computed as the difference score (B−A) and the ratio score (B/A).

2.3. General procedure

Testing took place in two sessions, administered individually over a 2-week period. Each session lasted approximately 1.5 h, for a total of 3 h. The order of task administration was fixed for all participants (with the constraint that no two tasks that were supposed to tap the same executive function occurred consecutively) to minimize any error due to participant by order interaction. The tasks administered in Session 1 were the MMSE, CDR, GDS, Stroop, Trail Making Test, COWAT-FAS, Rey Complex Figure, Digits Forward and Backward, Semantic fluency and Digit Symbol. Those administered in Session 2 were the PAL (Paired Associates Learning), Brixton test, Boston naming test and MCST.

2.4. Hypotheses

In common with Miyake et al.'s results, the WCST, the Brixton test, and TMT-B/A were expected to map onto the 'Shifting' component of the executive system, while Stroop (incongruent condition) was expected to load on both the 'Inhibition' and 'Updating' components. Although these expectations are based on Miyake et al.'s conceptual framework, it is possible that a different factor structure may emerge. With regard to the other measures, assuming that Miyake et al.'s partitioning generalizes to the age-related variance in executive tasks, it would be reasonable to assume that performance differences in the span measures and PAL would be associated with the 'Updating' component of the executive system (visuospatial component). With regard to processing speed, strong negative relationships were expected between the speed component and all the components of executive control. Finally, we expected long-term memory access to be statistically distinguishable from the others tapping onto executive control (following Fisk & Sharp, 2004). We predicted that age would have a high negative impact on this latent factor, presumably loading on measures requiring verbal fluency. Furthermore, indirect evidence of dedifferentiation of EFs would take the form of a two-factor or even a single-factor solution for our sample of healthy elderly adults (i.e., replicating the results of De Frias et al., 2006), but not a multifactor solution, because or sample of elderly adults cannot be labeled as cognitive elite (see De Frias, Dixon, & Strauss, 2009; De Frias et al., 2006), thus failing to reflect a potentially "maintained" multidimensional EF structure (Miyake et al., 2000).

2.5. Statistical analyses

To address the relationship of both age and processing speed with the latent components 'Shifting', 'Updating' and 'Inhibition' we adopted the structural equation modeling (SEM) approach advanced by Miyake et al. (2000), who established that these components are distinct, but correlated, at the latent level. Following this study, we employed SEM to evaluate an a priori specified measurement model of executive function that included several components as latent factors underlying age-related changes. Our latent variable approach provided purer measures in that the variance attributable to idiosyncratic task requirements is excluded, thereby reducing the task impurity problem. Furthermore, these latent variables can be more reliable because measurement error is excluded, and, hence, the correlations between latent variables are analogous to correlations corrected for attenuation due to unreliability (Bollen, 1989). Finally, the types of latent variable analyses used in the current study—confirmatory factor analysis (CFA) and SEM—differ from other multivariate techniques (e.g., exploratory factor analysis) that are data-driven and a posteriori. Because CFA and SEM require a model of the underlying functions contributing to each task to be specified before analysis, they do not necessitate post hoc explanation and are less likely to capitalize on chance. Thus, we had to depart from the Miyake et al.'s approach in that our measurement model included three latent factors and one modulating factor (Speed). Thus, these measures were retained as separate variables rather than aggregating them in a single common factor (for similar results see Van der Sluis, De Jong, & Van der Leij, 2004). The tasks were chosen primarily because they are frequently used as measures of the integrity of executive functioning among frontal lobe patients (i.e., COWAT, Brixton and PAL), because their role in measuring processing speed (Digit Symbol) and central executive functioning (i.e., MCST, TMT, Digit Backward).

2.5.1. Transformations and outlier analysis

To avoid computational problems that may arise when the variances of the variables differ greatly (as it is the case here), we rescaled the measurement variables by means of standardization. Rescaling the variables does not alter group differences in any meaningful way (i.e., the group differences in means and covariance structure are retained), albeit on a linearly transformed scale. With regard to the MCST, if performance was less than 70% correct on the Shifting task (MCST), the results from this particular task were coded missing. For all conditions (MCST) where RT served as a dependent measure, we performed a two-stage trimming procedure: (1) all incorrect responses, as well as responses that were preceded by an incorrect response, or responses with RTs shorter than 120 ms, or with a latency exceeding the mean by more than 2.5 standard deviations were excluded from the RT analyses. This amounted to less than 1.5% of all trials of the MCST, (2) extreme outliers at group-level per condition were identified by SPSS boxplot procedure (SPSS Inc., 2003). Extreme data (i.e., more than three times the inter-quartile range) were scored as missing. Failure to complete the first category of the MCST was scored as missing. Regarding to missing values, a listwise deletion method was implemented and no imputation method was applied.

2.5.2. Model fitting

Preliminary descriptive statistics for all the single observable variables of the model were performed to determine if the use of structural equation modeling on our data was appropriate. In addition, we tested for multivariate normality with PRELIS program. To assess the overall fit of SEM models we used χ^2, relative/normed χ^2 (χ^2/df), the Root Mean Square Error of Approximation (RMSEA), and its 95% confidence interval, the Standardized Root Mean Squared Residual (SRMR), and the Comparative Fit Index (CFI). A model can be considered to fit the data if χ^2 is statistically non-significant ($p \geqslant 0.05$), $\chi^2/df < 2$, RMSEA < 0.05, SRMR < 0.08, and CFI > 0.95. These indices and proposed cut-off points were chosen on the basis of their performance in previous Monte-Carlo simulations and recommendations based on these simulations (Hu & Bentler, 1999). To test single parameters, we adopted the 5% significance criterion (i.e., *t*-value of parameters of 2.00). Model fitting was done using LISREL 8.80 (Jöreskog & Sörbom, 2006) with maximum likelihood estimation method.

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3. Results

A summary of descriptive and correlational statistics for the measures used to tap the target executive factors (i.e., Shifting, Updating, Inhibition, and Access) is presented in Tables 1 and 2, respectively.

To examine each latent variable rigorously, we performed a set confirmatory factor analyses (CFAs) to statistically compare the fit of competing models including and dropping several variables to reach the best model fit. No correlated errors between pairs of tasks were considered for any tested model. In a second step, a three-factor model, a two-factor, and single-factor model, were also tested. Finally, the complete latent model was fitted and assessed.

3.1. CFA for the ''Speed'' latent variable

The CFA analysis of the latent factor representing processing speed was indexed by median RT of the pure blocks of the Stroop Word task, TMT-A and Digit Symbol. The paths between manifest and latent variables were .44, .75 and −.71 for the Stroop Word, Digit Symbol, and Trail Making Test-A, respectively. This model was further used as a mediating factor in the full latent model. As the three tasks are speeded tasks, these were specified to load on the basic processing speed factor to correct for within-group individual differences.

3.2. Series of CFA for the ''Shifting'' latent variable

A series of CFA were conducted to reach the best-fit model for the 'Shifting' latent variable. First, a model that included all four measures considered for the 'Shifting' model (Brixton Errors, Switch Cost, Efficient Series (MCST), and TMT (B/A)) was conducted, which provided a good fit ($\chi^2 = 2.73$; $df = 2$; $p = .255$; RMSEA = 0.055).

Table 1
Means, standard deviations (sd), Minimum (Min) and Maximum (Max) scores on the demographic and neuropsychological variables of the sample ($N = 122$).

	Mean	sd	Min	Max
Age	62.3	8.4	48	91
Education (years)	11.3	3.7	2	19
CDR	0.03	0.1	0	0.5
MMSE	29.1	1.1	28	30
GDS	7.8	5.1	0	14
Stroop Word	96	16.7	54	143
Stroop Color	63.3	12.7	20	94
Stroop Color-Word	36.2	10.1	10	65
TMT-A	41.1	17.6	15	113
TMT-B	99	63	34	461
TMT B/A	2.4	0.9	1	6
Digits Forward	8.4	2.3	4	16
Digits Backward	5.9	2.1	2	11
Span Forward	4.7	1.3	2	8
Span Backward	3.4	1.2	1	6
Rey Copy	34	3.5	17	36
Rey Memory	17.9	6.7	2	34
Boston test	53.9	5.4	40	60
COWAT-FAS	35.2	11.9	8	80
Semantic fluency	20.6	5.3	10	37
Brixton (errors)	17.1	6.3	4	34
Efficient (MCST)	8.4	2.7	0	12
Set-Loss (MCST)	2.2	1.7	0	8
Perseverative (MCST)	0.9	1.3	0	6
Switch Cost (MCST)	69.3	112.7	−232	407
Digit Symbol	54.2	16.5	16	97

Note: CDR = Clinical Dementia Rating Scale; MMSE = Mini-mental State Examination; GDS = Geriatric Depression Scale; TMT = Trail Making Test; Span Forward = Digit Span Forward, Span Backward = Digit Span Backward, COWAT-FAS = Controlled Word Association Task; MCST = Madrid Card Sorting Test.

With the aim in mind of providing three neuropsychological measures for each proposed latent variable as a more parsimonious approach, we conducted different series of CFAs for the 'Shifting' variable and explored the goodness of fit of each one. Given that a CFA with three observed variables was saturated, and consequently, all indices denoted perfect fit, we used a reliability index to select the best model. Four CFA ''Shifting' models were tested: (1) a CFA model including Switch Cost, Efficient MCST Series, and Trail Making Test (B/A), (2) a CFA including the measures of Brixton Errors, Efficient Series (MCST) and Trail Making Test (B/A), (3) a model including Brixton Errors, Switch Cost (MCST) and Trail Making Test (B/A), and (4) a fourth CFA model that comprised the measures of Brixton Errors, Efficient Series (MCST) and Switch Cost (MCST). Following the mean maximum reliability values, the manifest variables, which composed the 'Shifting' latent model, included the Switch Cost (MCST), Efficient Series (MCST) and the Trail Making Test (B/A). Path loadings between manifest variables and latent variable were −.25, .41 and −.78 for Switch Cost, Efficient Series (MCST) and TMT (B/A), respectively. Despite these results, a reasonable doubt may persist regarding the structure of indicators of this latent variable. Therefore, subsequent analyses with the full latent model seek to select the best composition for 'Shifting' (see section 3.4.1. for model results regarding the 'Shifting' latent variable).

3.2.1. A common CFA for 'Working Memory' (subsuming 'Inhibition' and 'Updating')

Measures included for both the 'Inhibition' and 'Updating' factor were best represented by a common latent variable, which we labeled as 'Working Memory'. Given that the latent factors 'Updating' and 'Inhibition' showed only moderate loadings (for instance, Digit Backward and Stroop Color-Word were the only measures tapping onto each latent factor, respectively), these were added to a common latent factor of 'Working Memory'. Of importance is to note the high correlation between Digits and Stroop Color-Word, which was .38 (see Table 2). The manifest variables that composed the latent variable 'Working Memory' included the measures of Digits Forward, Stroop Color-Word, and PAL (errors at the six-element stage). Factor loadings with the latent variable were .50, .67 and −.40 for Digits Forward, Stroop Color-Word, and PAL (errors at the six-element stage), respectively. Because this model was saturated (three indicators), goodness of fit indices indicated a perfect fit.

3.3. CFA for the latent variable ''Access''

The CFA model representing 'Access' as a latent variable included the measures of the Boston test, the COWAT-FAS, and Semantic fluency. After fitting the CFA model, factor loadings were .70, .71 and .68, respectively.

3.4. Full latent models analyses

3.4.1. Full latent model comparison strategy according to different ''Shifting'' structures

The results of the following sections represent four tentative full models and the best model following a model comparison strategy. With the aim of further confirming the best-fit option with regard to the 'Shifting' latent variable, we now present four full preliminary models, each one after dropping one manifest variable of the 'Shifting' latent variable: (a) Brixton Errors, (b) Switch Cost, (c) Efficient Series of the MCST, and (d) TMT B/A. The full structural reduced model after dropping Brixton Errors from the 'Shifting' latent variable yielded an non-acceptable fit ($\chi^2 = 110.18$; $df = 62$; $p = .00153$; RMSEA = 0.071), and was therefore discarded from further discussion. The second model, where Switch

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Table 2
Correlation matrix. Pearson product-moment correlations between demographic and neuropsychological measures.

	Age	Gen	Edu	CDR	MMSE	GDS	Sp	Sc	Scw	Tmt-a	Tmt-b	B/A	For	Back	Sfor	Sback	Reyc	Reym	FAS	Berr	Effi	Loss	Per	DS	Cost	An
Age	1.00																									
Gen	−.17	1.00																								
Edu	−.01	−.34**	1.00																							
CDR	.19*	.01	−.12	1.00																						
MMSE	−.31**	−.07	.19*	−.52**	1.00																					
GDS	−.09	.11	−.20*	.31**	−.29**	1.00																				
Sp	−.23*	−.02	.11	−.14	.16	−.15	1.00																			
Sc	−.31**	.15	.19*	−.26**	.20*	−.29**	.59**	1.00																		
Scw	−.31**	.01	.20*	−.25*	.24*	−.22*	.41**	.71**	1.00																	
Tmt-a	.34**	.19*	−.15	.32**	−.41**	.25*	−.31**	−.41**	−.47**	1.00																
Tmt-b	.44**	.13	−.18*	.29**	−.49**	.24*	−.40**	−.48**	−.51**	.71**	1.00															
B/A	.30**	−.01	−.11	.17	−.24*	.10	−.24*	−.26**	−.24*	−.04	.61**	1.00														
For	−.13	−.16	.27**	−.28**	.21*	−.10	.18*	.26**	.33**	−.32**	−.30**	−.12	1.00													
Back	−.18*	−.17	.29**	−.38**	.37**	−.22*	.24*	.32**	.38**	−.40**	−.42**	−.23*	.60**	1.00												
Sfor	−.13	−.20*	.24*	−.27**	.19*	−.04	.17	.22*	.29**	−.34**	−.29**	−.08	.95**	.57**	1.00											
Sback	−.16	−.17	.24*	−.41**	.37**	−.20*	.22*	.30**	.35**	−.39**	−.41**	−.22*	.58**	.96*	.54**	1.00										
Reyc	−.10	−.09	.17	−.14	.28**	−.14	.16	.23*	.25*	−.27**	−.37**	−.23*	.28**	.36**	.26**	.36**	1.00									
Reym	−.29**	−.28**	.33**	−.37**	.29**	−.20*	.12	.23*	.32**	−.31**	−.43**	−.35**	.24*	.40**	.28**	.40**	.42**	1.00								
FAS	−.07	−.23*	.37**	−.26**	.19*	−.27**	.29**	.36**	.39**	−.44**	−.37**	−.06	.39**	.41**	.35**	.37**	.13	.31**	1.00							
Berr	.20*	.20*	−.18*	.41**	−.31**	.23*	.05	−.18	−.28**	.33**	.39**	.22*	−.29**	−.54**	−.28**	−.55**	−.22*	−.42**	−.36**	1.00						
Efi	−.31**	.14	.15	−.31**	.34**	−.19*	.17	.40**	.35**	−.29**	−.49**	−.39**	.28**	.29**	.26*	.28*	.12	.24*	.25*	−.25*	1.00					
Loss	.16	−.01	−.21*	.24*	−.37**	.19	−.01	−.27*	−.26*	.21*	.36**	.31**	−.30**	−.31**	−.28**	−.29**	−.11	−.25*	−.29**	.25*	−.80**	1.00				
Per	.26*	−.17	.00	.27**	−.11	.16	−.19*	−.32**	−.27**	.17	.29**	.24*	−.16	−.14	−.14	−.14	−.08	−.13	−.03	.09	−.68**	.18	1.00			
DS	−.36**	−.25*	.39**	−.36**	.46**	−.31**	.34**	.54**	.58**	−.58**	−.66**	−.40**	.34**	.51**	.30**	.49**	.32**	.52**	.53**	−.43**	.43**	−.35**	−.28*	1.00		
Cost	.22*	−.02	.04	.02	−.03	.02	−.28**	−.22*	−.25*	.21*	.28**	.20*	−.19*	−.26**	−.15	−.24*	−.13	−.12	−.19*	.07	−.09	.01	.12	−.30*	1.00	
An	−.19*	−.08	.24*	−.31**	.32**	−.15	.24*	.29**	.29**	−.44**	−.37**	−.07	.31**	.41**	.30**	.37**	.15	.39**	.48**	−.19*	.35**	−.30**	−.20*	.42**	−.09	1.00

Notes: Gen = Gender; Edu = Education; CDR = Clinical Dementia Rating scale; MMSE = Mini-Mental State Examination; GDS = Geriatric Depression Scale; Sp = Stroop Word; Sc = Stroop Color; Scw = Stroop Color-Word; Tmt-a = Trail Making Test-A; Tmt-b = Trail Making Test-B; B/A = Trail Making Test ratio score; For = Digits Forward; Back = Digits Backward; Sfor = Span Forward; Sback = Span Backward; Reyc = Rey Complex Figure (copy); Reym = Rey Complex Figure (memory); FAS = Controlled Word Association Task; Berr = Brixton errors; Effi = MCST number of Efficient series; Loss = MCST number of Set-Loss errors; Per = MCST number of Perseverations; DS = Digit Symbol; Cost = MCST Switch Cost; An = Semantic fluency (animals).

* $p < .05$.

** $p < .01$.

Cost was dropped, showed also a non-acceptable fit ($\chi^2 = 115.41$; $df = 62$; $p = .000045$; RMSEA = 0.471), and was also discarded. In third place, the full structural reduced model after dropping the Efficient MCST Series from the 'Shifting' latent variable did not meet statistical criteria ($\chi^2 = 110.9$; $df = 62$; $p = .00013$; RMSEA = 0.081), which made us discard it from further analysis and discussion. Finally, the structural model comprising the manifest measures of Switch Cost, Efficient MCST Series, and Brixton Errors, yielded the best fit ($\chi^2 = 81.52$; $df = 62$; $p = .04896$; RMSEA = 0.051). This made us consider this model as the best 'Shifting' latent structure.

3.4.2. CFA structure with the latent variables "Shifting", "Working Memory" and "Access"

Prior to the estimation of the final full latent model, results of a CFA for a structure with the optimized latent variables 'Shifting', 'Working Memory', and 'Access' are presented. This model, depicted in Fig. 1, yielded a good fit ($\chi^2 = 19.86$; $df = 24$; $p = .70$; $\chi^2/df = 0.83$; RMSEA = 0.00; p[RMSEA < 0.05] = 1.00; RSMR = 0.043; CFI = 1.00). This good overall fit obtained for this CFA model denotes that all linked tasks to the three latent variables get a correct multivariate behavior. From this good fit we could build more accurately the full latent model, which included age and speed of processing.

3.5. Three-factor adjusted model

The adjusted model that incorporated three latent variables ('Shifting', 'Working Memory' and 'Access'), and one modulating latent factor ('Speed') provided an acceptable description of executive functioning task performance and a good overall fit ($\chi^2 = 75.86$; $df = 59$; $p = 0.068$; $\chi^2/df = 1.3$; RMSEA = 0.049; p[RMSEA < 0.05] = 0.5056; SRMR = 0.05987; CFI = 0.9756). The SEM analyses indicated that the latent factors 'Shifting', 'Working Memory' and 'Access', were separable but related to each other, due to their high correlations (see Fig. 2). 'Shifting' was highly correlated with 'Working Memory' (−.95) and 'Access' (−.84), and a high correlation was also estimated between 'Working Memory' and 'Access' (.83) (see Fig. 1). These results provide additional support for the non-unitary nature of executive functioning (Fisk & Sharp, 2004; Miyake et al., 2000). Most importantly, however, is that the current study added an age-related approach to the executive functioning, which is strongly modulated by processing speed.

A summary of results for the mediation analyses based on the model portrayed in Fig. 2 shows that the three cognitive constructs ('Shifting', 'Working Memory' and 'Access') have very high correlations with speed of processing (−.96, .97 and, .95, respectively). Moreover, the correlation between 'Speed' – which was expected to represent a potential mediator between age and executive control – and age, was also high (age–speed correlation was −.46). Inspection of the model values reveals that all of the direct age-related effects were statistically non-significant, as compared to the corresponding indirect age effects (mediated by 'Speed', see Fig. 2, dotted lines). It is noteworthy that the results presented in Fig. 2 are consistent with the expected mediational pattern, but these cannot necessarily be interpreted as evidence that one construct is a true mediator of the age-related effects. That is, if the constructs represent nearly the same dimension of variation, as is likely the case when the correlation between them is very high,

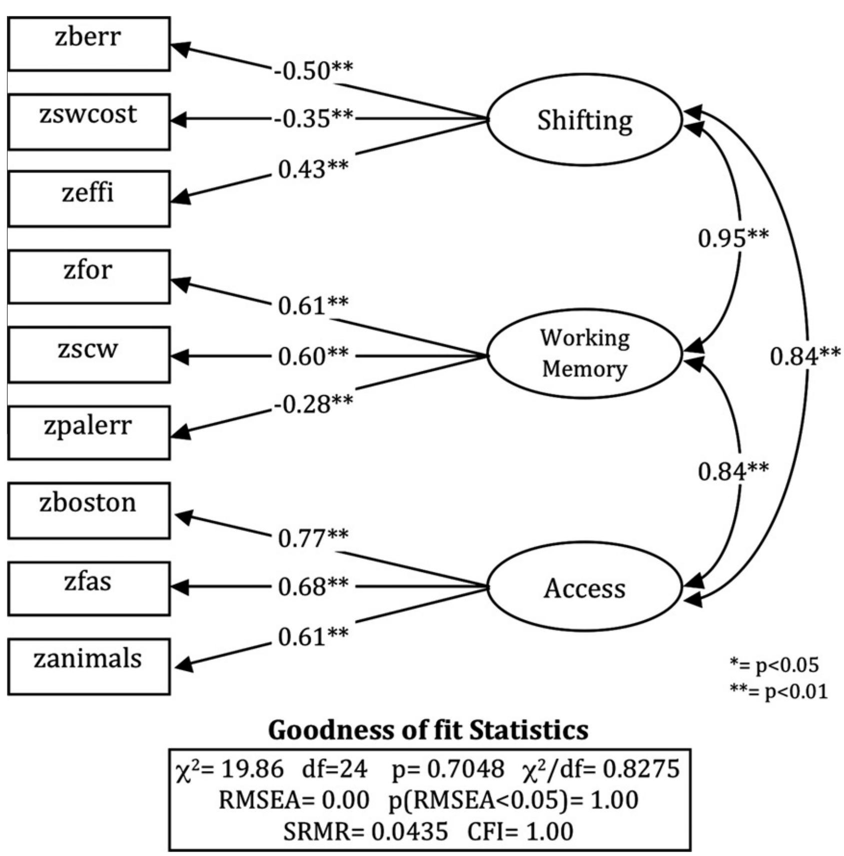

Fig. 1. CFA model for 'Shifting', 'Working Memory', and 'Access'. Note: zberr = number of errors in the Brixton test, zswcost = Switch Cost in the MCST, zeffi = number of Efficient Series in the MCST, zfor = span in the Digits Forward Test, zscw = number of correctly named items in the Stroop Color-Word, zpalerr = number of errors at the 6-element stage of the PAL, zboston = number of correctly named items in the Boston test, zfas = total number of correctly produced nouns in the Controlled Word Association Test, zanimals = number of correctly produced words in the Semantic fluency test.

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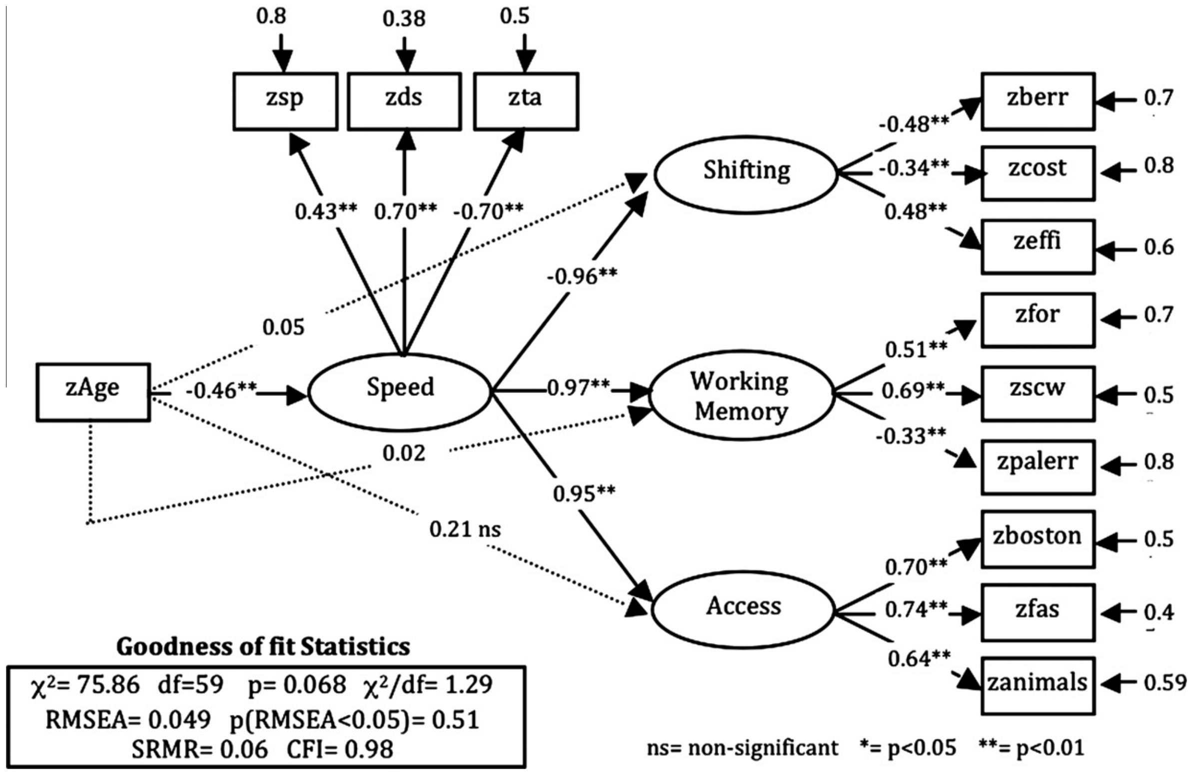

Fig. 2. Three-factor latent model with 'Shifting', 'Working Memory' and 'Access', and 'Speed' as mediating variable. Dotted lines represent direct non-significant effects of age on each latent executive variable. Note: zage = age, zsw = number of words in the Stroop Test, zdsym = number of items in the Digit Symbol Test, zta = time in performing the Trail Making Test-A. The rest of abbreviations are the same as in Fig. 1.

then the analyses may in effect be partialling out the construct from itself, in which case it might not be meaningful to refer to mediation.

3.5.1. Two-factor adjusted model

The adjusted model that incorporated two latent variables ('Working Memory' and 'Access'), and one modulating latent factor ('Speed') also provided an acceptable description of executive functioning and a good overall fit (χ^2 = 75.49; df = 61; p = 0.1003; χ^2/df = 1.24; RMSEA = 0.044; p[RMSEA < 0.05] = 0.59; SRMR = 0.06; CFI = 0.98), that was even better that the model including a three-factor solution. All indices indicated an adequate fit (Fig. 3). The SEM analyses indicated that the latent factors 'Working Memory' and 'Access' were separable but related to each other, due to their high correlations (correlation between 'Working memory' and 'Access' was −.83).

3.5.2. Single-factor adjusted model

The adjusted model that incorporated a single latent variable ('Working Memory'), and one modulating latent factor ('Speed') did not provide an acceptable description of executive functioning (χ^2 = 88.36; df = 63; p = 0.019; χ^2/df = 1.40; RMSEA = 0.058; p[RMSEA < 0.05] = 0.31; SRMR = 0.065; CFI = 0.96). Thus, this model did not better represent EF in older adults than models including both three-, and two-factor solutions (see Fig. 4).

4. Discussion

We have examined the organization and roles of three putative executive functions at the level of latent variables, rather than at the level of manifest variables (i.e., individual tasks) in a large sample of healthy elderly participants. The first major goal was to try to replicate Miyake et al.'s findings about the unity and diversity of three executive functions (e.g., Shifting, Updating, Inhibition), and to specify their relative contribution to some classic as well as some newer complex tests routinely used to assess executive functioning. The second aim of this study was to examine whether these three latent variables could be hierarchically related among themselves or even with a fourth dimension considered specific to cognitive ageing. Our results provide support for the non-unitary, multi-faceted nature of executive functioning, and are consistent with other studies taking a latent variable approach and showing separable executive components (e.g., Baena, Allen, Kautb, & Hal, 2010; Fisk & Sharp, 2004; Huizinga et al., 2006; Lehto, Juujaervi, Kooistra, & Pulkkinen, 2003; Miyake et al., 2000; Vaughan & Giovanello, 2010).

Our results have several implications regarding the organization of executive functioning in healthy elderly participants, and suggest that EF is best described as consisting of at least two distinct, yet related, subcomponent processes rather than as a purely unitary process. EF could be described by (1) a model representing the subcomponent processes of 'Shifting', efficiently maintaining representations in working memory ('Working Memory'), and a separate subcomponent process representing the retrieval of contents from long-term memory ('Access'); and (2) a two-factor solution representing 'Working Memory' and 'Access'. As in Hedden and Yoon (2006), 'Inhibition' could not be identified as a separate factor. Importantly, we show that the age-related cognitive decline in EF is strongly mediated by 'Speed', even at the latent level, and that word fluency (together with Semantic fluency) loads on a distinct factor ('Access'), that could perhaps reflect an additional executive process (see Fisk & Sharp, 2004). Here we suggest that word fluency is a measure of the efficiency with which items from long-term memory can be accessed and retrieved. Contrary to Fisk and Sharp (2004), who did not find a relationship between word

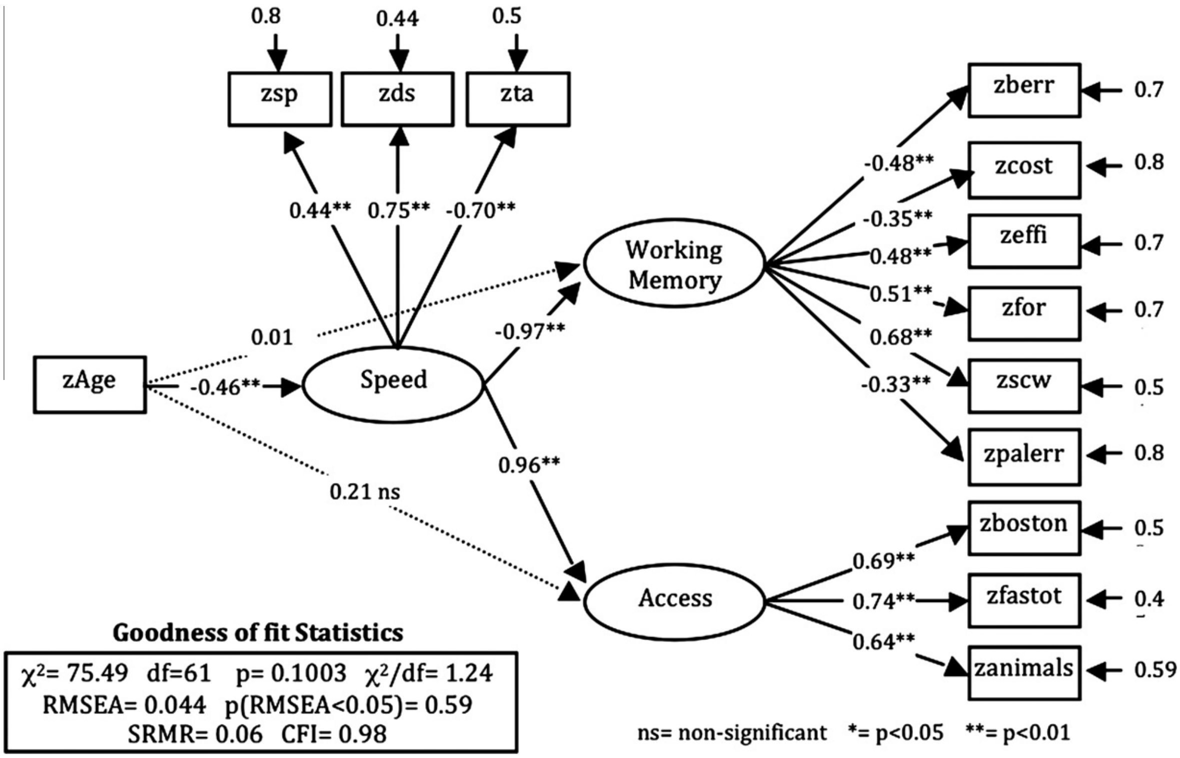

Fig. 3. Two-factor latent model with 'Working Memory' and 'Access', and 'Speed' as mediating variable. Dotted lines represent direct non-significant effects of age on each latent executive variable. Abbreviations can be consulted in Figs. 1 and 2.

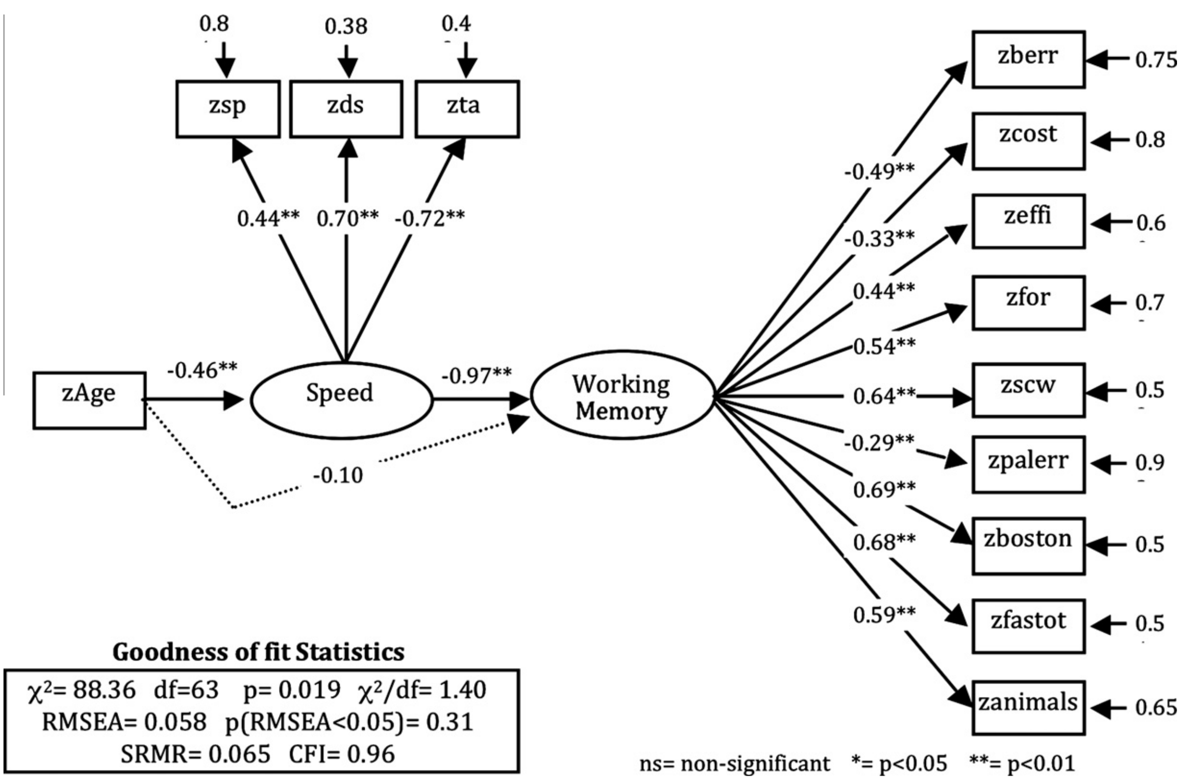

Fig. 4. Single-factor latent model with 'Working Memory', and 'Speed' as mediating variable. Dotted lines represent direct non-significant effects of age on each latent executive variable. Abbreviations can be consulted in Figs. 1 and 2.

fluency and age, (they stated that access to long-term memory was preserved in old age) we now show a moderate direct influence of age on 'Access' (−.21), which was indeed the latent variable most directly compromised by age itself. It is also important to point out that the low direct correlations between age and 'Shifting', and between and age and 'Working Memory' (.005 and .002,

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respectively), show that their decline during ageing is strongly mediated by 'Speed', and not by age itself.

Importantly, in our sample of healthy older adults (as reported in De Frias et al., 2006), we observe signs of a less heterogeneity of EF structure than that found in Miyake et al. (2000). Of note is that in the three-factor model, the correlations between the latent variables were high, which was reflected in a better fit for the two-factor model, (but not for the single-factor model). Therefore, we find support for diversity of EF in healthy ageing, although this is qualified by shared variances between factors. Finally, we don't find evidence for a single dimension of EF, at least as measured by the present variables (see Fig. 4). Thus, our sample of elderly adults shows a slight dissolution of EF. In sum, we report that 'Shifting' and 'Updating' are best treated as a single process in elderly adults, although the findings reported by Miyake et al. (2000) showed a distinction between these two subcomponents, which had a correlation of .56 in their study. The larger correlation between these constructs in our study may have been related to the restriction of the sample to older adults, who sometimes exhibit 'dedifferentiation', or increased relationships among cognitive variables (Antsey et al., 2003; Ghisletta & Lindenberger, 2003).

4.1. Age-related influence of processing speed on executive control

The processing speed tasks used in the present study are widely used in literature on cognitive ageing, and their reliability and validity are well established. In this vein, Salthouse and others have demonstrated their role in attenuating age-related differences in a broad range of cognitive measures (see Salthouse, 1996, for a review). However, the tasks employed here are more than simple reaction time measures, and similar tasks have been shown to recruit prefrontal activity and, presumably, executive resources (Cohen, Botvinick, & Carter, 2000). Therefore, it is not surprising that they share variance with the putative executive factors identified in the present study. More generally, it is worthy of note that 'Speed' is significantly correlated with a large set of the measures employed in this study, even though the correlations between the measures themselves may not be very high (TMT-A and Stroop Words = −.31**; TMT-A and Digit Symbol = −.58**, Stroop Words and Digit Symbol = .34**, see Table 2).

This finding is in line with the results reported on some classic cognitive ageing studies, which have found very little direct age-related direct influences on working memory and updating (see Salthouse, 2001, for details). We interpret this finding to mean that the more complex the speed task is, the more it relies on executive or working memory resources, and then the more shared age-related variance between speed and executive variables. Therefore, our results suggest that the tasks used to measure processing speed may have tapped into executive processes to some degree, and the speed mediation of age-related differences might be derived from loadings of the speed measures on the executive components.

4.2. A common factor behind 'Inhibition' and 'Updating' of information

In the present study, we could not identify a distinct latent construct representing Inhibition, as it was the case in Hull et al. (2008). This suggests that Inhibition may be less fundamental in understanding susceptibility to interference than are other executive subcomponents. Indeed, Inhibition may represent not a single mechanism, but rather a diverse set of mechanisms that contribute differentially to different aspects of cognition (Friedman & Miyake, 2004). Although older adults may be impaired in some types of inhibitory function (Hasher et al., 1991; Lustig, May, & Hasher, 2001), the consequences of this impairment may be smaller than the consequences of age-related impairments in 'Shifting' and functions related to 'Working Memory'. The failure to find a single inhibitory construct may be a consequence of less coherence among individual measures of inhibitory function, as several studies have reported relatively weak relationships among measures of inhibition (Davidson & Glisky, 2002; Shilling, Chetwynd, & Rabbitt, 2002).

Our view is that WM span tasks involve joint contributions of a general executive-attention capability and domain-specific rehearsal, coding, and storage processes. Of importance, the shared variance among measures of Working Memory and Inhibition reflects the contribution of a domain-general attention control mechanism (e.g., Engle & Kane, 2004; Engle, Kane, & Tuholski, 1999). We argue that the critical executive capability is one by which memory representations are maintained. Accordingly, span tasks elicit such active maintenance by providing proactive interference that accumulates over trials, making retrieval difficult and slow (e.g., Lustig et al., 2001). Therefore, we have used the term *Working Memory* to refer to the domain-general executive component of the working memory system, which also included the Stroop Color-Word. Thus, both measures (Digits and Stroop Color-Word), together with PAL, loaded in the same latent variable. In line with these claims, participants that in several works were rated as 'high' in working memory span capacity, were either faster or less error prone when performing the Stroop test than were 'low span' participants, depending on task context (Kane & Engle, 2003; Long & Prat, 2002). Of importance is that the Stroop task is pertinent in the 'Working memory' latent variable since it demands that participants block a prepotent response in favor of a novel goal-directed one, in our view by using executive attention to actively maintain the goal (see also De Jong, 2001; Duncan, 1995).

Performance in these tasks, with either verbal (Digit Forward and Stroop Color-Word) or visuospatial materials (PAL), reflects one's ability to encode, maintain, and retrieve lists of isolated stimuli. Our interpretation is consistent with a view of a domain-specific storage and rehearsal processes that contributes to task performance; but a domain-general, and attentional–executive aspect of the latent variable may drive the correlations between the Digit Forward, Stroop Color-Word, and PAL measures (for similar ideas, see Engle & Kane, 2004; Engle et al., 1999). Moreover, the maintenance of information in working memory is particularly important in the presence of interference (presumably represented by the Stroop Color-Word), which disrupts rapid retrieval of information (Engle & Kane, 2004; Kane & Engle, 2000, 2003). Furthermore, interference may also reflect the time-consuming process of resolving response competition in service of a successfully activated goal to do so, which should lead to a consistent slowing on incongruent trials (as shown by the .97 path factor between 'Speed' and 'Working Memory', depicted in Fig. 3). Our results point out that normal ageing produces particular difficulties with active goal maintenance through the mediation of processing speed. Accordingly, Kane and Engle (2003) demonstrated that measures of working memory span predict Stroop interference scores. Furthermore, our structural model also implies that goal maintenance is partly related to visuospatial memory (PAL).

4.3. Relationships between latent variables

While the relationship between 'Speed' and the EF factors is strong and significant, age does not significantly predict executive functioning; these findings appear to provide empirical evidence to support the executive decline in cognitive ageing, which is mediated by the modulating factor of speed of processing. The close relationship between 'Speed' and 'Shifting' points the relevance to Salthouse's (1996) decomposition of age-related changes in processing speed. Specifically, the discovery that there were large path loadings among variables 'Speed' and 'Shifting' when increased age was postulated to affect speed, suggests that the 'Speed' construct may be more fundamental than the 'Shifting' construct. The negative relationship with age indicates that increased age was associated with lower levels of what all variables had in common, and the small number of independent or direct relations from age to individual variables suggests that for most of the variables almost all of the age-related influences were shared with other variables. Further, the negative correlation between both latent variables might imply a trade-off between 'Shifting' and 'Speed'.

However, the 'Shifting' measures were found to have reliable individual variance independent of the other 'reaction time' measures (which composed the 'Speed' latent variable), suggesting that they represented a distinct construct. The close relationship between 'Speed' and 'Shifting' can be explained backing up the evidences provided by Salthouse et al. (1998), who reported that when reaction times are statistically controlled, there might no longer be any significant relations of switching either to age or to measures of higher order cognition.

The implication of this result is that, although 'Shifting' can be identified as a distinct construct, most its relations with other variables are shared and are not unique to 'Shifting'. In turn, many studies have failed to find the purported age-related effects on local switch costs after controlling for task preparation, practice, and general motor slowing (Cepeda, Kramer, & Gonzalez de Sather, 2001; Kray & Lindenberger, 2000; Mayr, 2001; Meiran, Gotler, & Perlman, 2001; Salthouse et al., 1998, see Braver & West, 2008, for a review), while others have found both advanced age and low cognitive control to marginally enhance task-switch costs (Adrover-Roig & Barceló, 2010). One cause for these inconsistencies could be a plausible confound between specific and non-specific sources of task-switch costs, such as those associated with the infrequent task cues in intermittently-instructed task-cueing paradigms. These accounts are compatible with a general-purpose mechanism for the resolution of task uncertainty, whenever the infrequent cues prompt for a decision about whether to switch or to repeat the previous task rule (Barceló, Perianez, & Nyhus, 2008). Hence, the behavioral cost measured after an infrequent task-switch cue could well reflect a combination of general and specific task-switching mechanisms (Salthouse et al., 1998).

Our results reinforce the idea that prefrontal-related processes of elderly adults are uniformly less efficient than those of younger adults—a pattern consistent with West (1996). However, it should be noted that our SEM results also suggest that these prefrontal age deficits cannot be sufficiently explained using a single common factor as one might expect from West's model. As in Baena et al. (2010), we suggest four distinguishable latent constructs, including the additional factor of retrieval (labeled as 'Access', in the present study). Further, the present study may be viewed as extending the executive-function work of Hull et al. (2008), given that these authors factor-analyzed executive tasks for just older adults and observed such a pattern of process-specific results. Importantly, as reported in Baena et al. (2010) (Model 2), a higher order common factor raised in the full latent model ('Speed', see Figs. 2 and 3), thus implying that performance on the four latent factors was driven by a common age-related phenomenon. Certainly, these results must be considered within the context of known alterations to widespread regions of brain (e.g., fronto-parietal, medial temporal), thus raising the issue of global network changes influencing performance rather than simply a localized decline in prefrontal-related processes (see discussion in Greenwood, 2000). Nevertheless, we offer additional support to the extensive literature defining the central role of executive alterations in age-related neuropsychological decline (Dennis & Cabeza, 2008; West, 1996). However, older adults show deficits not only in executive-function tasks, but also in processes that involve the long-term memory access. In all, the finding that the optimal SEM model was factor-specific in nature suggests that age differences in prefrontal function are more consistent with independent or process-specific models (Figs. 2 and 3) of cognitive ageing (Hull et al., 2008), than with a generalized common factor model (e.g., Salthouse et al., 1998).

4.4. Comparison with Miyake et al.'s study

There are several differences in findings between our study and Miyake et al.'s (2000), which might be partly due to the fact that we have included some new extra measures that have been shown to be valid indexes of executive functioning. Also, the lack of cohesiveness among our 'Inhibition' measures and the consequential failure of these to indicate a latent construct, may indeed reflect a deficit in inhibition in older adults. However, that would necessitate not only a lower level of performance on inhibition tasks, but also less variance in its indicators relative to those obtained by Miyake et al. (2000). This appeared to be the case for the inhibition measures that overlapped across studies (i.e., Stroop). The standard deviation for the raw score Stroop measure was 10.1 in the present study and 60 in the Miyake et al. study. Similarly, the raw score standard deviation of the Number–Letter and Local–Global tasks in Miyake's study were 250 and 160, respectively, and 112 in our measure of Switch Cost. It remains possible, however, that even though the standard deviations were lower in our study, one or both of these measures were mainly tapping something other than 'Inhibition' in the older adult sample. Another possibility may rest in the fact that our 'Inhibition' measures involved prepotent response inhibition, and none required resistance to proactive interference, as in Miyake et al. (2000). However, the magnitude of significant relationships among the indicators in the Miyake et al. study was somewhat smaller for the Inhibition indicators (.19), as compared with the 'Shifting' (.29) and 'Updating' indicators (.31). Of importance is to note that in Mikaye's work, the second best model fit (Model 5, p.71) was the one that considered together the 'Updating' and 'Inhibition' factors, as it is the case of our study. We also think that our model represents well the latent factors studied, given that loadings of each variable were higher than those on Mikaye's study (see Fig. 3).

In line with our claims, the Stroop variable in Miyake et al.'s study was significantly related to two of their 'Updating' indicators ('Working Memory', in our case). In this light, it seems possible that tasks targeting prepotent response inhibition may not be particularly robust measures of the 'Inhibition' latent variable, particularly in older adults, and thus may have been inadequate to identify the latent factor. As in Miyake et al. (2000), the primary predictor for 'Shifting' was the MCST (.48 in Efficient Series), with similar path loadings (.38 for Perseverative Errors, see p.75 of Miyake's study). It is possible that the slightly different outcomes stem from differences in some of the measures used to identify the underlying factors, but a more interesting possibility is that the reduction in working memory capacity in older adults (e.g., Braver et al., 2001) causes an increased reliance on the 'Updating' skill, which seems to most directly represent 'Working Memory' capacity (see Engle & Kane, 2004). Given that 'Inhibition' and 'Updating' correlated .56 in Miyake's study, it is reasonable to consider that both constructs might constitute a unique factor, as it is the case in the present study. However, it may also have been due to the restriction of the sample to older adults, who sometimes exhibit "dedifferentiation," or increased interrelationships among cognitive variables (Antsey et al., 2003). Together with the older age range in the present study, the correlations among the executive function subcomponents were higher as those reported in samples of college-aged adults (as in Miyake et al., 2000) and in samples including adults between the ages of 18 and 84 (Salthouse et al., 2003). The congruence of the current results with those from other samples supports the general pattern regarding age differences in

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structural models of cognitive function. Importantly, although the pattern of loadings and constructs has generally been found to be age invariant, we report age-related differences in the relationships between indicators and the constructs measured with older adults (see also Nyberg et al., 2003). In sum, because this study was conducted on a sample of non-demented, predominantly Caucasian older adults with relatively high levels of education, some caution must be exercised when generalizing these results to other populations commonly examined by this research paradigm, such as college students or neurological patients. We believe that our work brings newer insights to the literature on cognitive ageing because of the well-known utility of newer tests, such as the PAL and the Brixton in documenting neuropsychological declines in older adults. Thus, these newer neuropsychological measures are likely to remain an important component in future studies of age-related declines in executive functioning.

Our results indicate that executive function is made up of subcomponent processes, including 'Shifting' between relevant task goals, maintaining representations in 'Working Memory' free of interference, and the 'Access' to long-term from memory contents (see Figs. 2 and 3). These executive components appear to vary independently, rather than jointly, in elderly individuals. Although the latent factor of 'Access' was not intended to be identified in Miyake's study, they further reported that both the phonological loop and the visuospatial sketchpad were identified as important contributors to fluency performance (long-term memory access), especially to performance on letter fluency and category fluency tasks, respectively, suggesting that the executive control may be deployed to perform both types of tasks (Rende, Ramsberger, & Miyake, 2002).

In sum, a single factor solution is insufficient to explain executive function performance, as was also found by Miyake et al. (2000). However, our results points to the apparent absence of a third factor that was detected for young adults, namely, Inhibition, (see Hull et al., 2008, for similar results). Further, the present results are consistent with the consideration that the relative contributions of multiple underlying factors may suffer from an age-related change. We think it is important to note that despite the high correlations among executive function subcomponents (.42, .56 and −.63 in Miyake et al., 2000; and .95, 84 and .84 in the current study), models that consider executive functioning as a single construct tend to fit the data more poorly than do models that propose distinct subcomponents of executive function (see Fig. 4). Finally, our results are in line with those of Hedden and Yoon (2006), who found a two-factor model of EF (both subsuming 'Updating' and 'Shifting') which contends against Miyake et al.'s (2000) three-factor model. As in Hedden and Yoon (2006), we used rather complex executive measures (WCST and the Brixton test in our case, WCST and TMT in Hedden and Yoon's) as indicators of 'Shifting', whereas Miyake et al. used simpler tasks as indicators. In general, complex tasks are diverse with regard to the executive functions they tap (see Miyake et al. for a discussion), and the WCST may involve different factors in older and younger adults. Thus, the inclusion of WCST and the TMT in the Hedden and Yoon's study and the MCST and the Brixton test in ours may have reduced the unique variance associated with the 'Shifting' factor. Is it also possible that both Hedden and Yoon's (2006) and our results regarding the reduction of 'Shifting' and 'Updating' to a single factor in older adults reflects support for the dedifferentiation hypothesis, as previously introduced (see Fig. 3). However, Hedden and Yoon (2006) argued that instead of a dedifferentiation process, the age-related cognitive decline may relate to individual differences in working memory.

Further, the age differences in 'Shifting' ability, which have been particularly linked to increasing global switch costs (i.e., the cost difference between task-switching blocks and single-task blocks), but not local shift costs (differences between switch and non-switch trials within blocks with predictable switch sequences) provide evidence in favor of this view (e.g., Kray & Lindenberger, 2000; Mayr, 2001). However, we have recently demonstrated that local switch costs both increase with advancing age when combined with a low level of cognitive control in elderly adults (Adrover-Roig & Barceló, 2010) and contribute to the 'Shifting' latent variable. These evidences, together with the lack of fit of a single factor representing working memory, contends against the interpretation given by Hedden and Yoon (2006), and puts into perspective their results with those of Miyake et al. (2000). Finally, as in Hull et al. (2008), our results indicate that different kinds of executive function tasks are differentially supported in older adults by at least two largely separable factors (i.e., 'Updating' and 'Shifting' in Hull et al. (2008), 'Working Memory' and 'Access' in our case). The absence of a third factor that was detected for young adults, contrary to Hull's interpretation, supports the dedifferentiation process in healthy ageing, which can operate on still separate executive processes responsible of working memory and access to long-term memory contents.

Continued research into the neuropsychological underpinnings of cognitive vulnerabilities among older adults will be of particular value for developing more explanatory models of the ageing brain and to gain insight into adaptive challenges or even threats with advancing age. In particular, we believe that it is important to more precisely determine the influence of age in long-term memory access using a latent variable approach. These processes are likely to converge on the frontal lobes, and are likely to be relevant to future studies of ageing. However, further studies adopting a longitudinal approach studies to establish this with certainty.

Acknowledgments

Funded by Grants PRIB-2004-10136 and PCTIB-2005-GC2-08 from Direcció General R + D + I, Govern de les Illes Balears, and SEJ2007-61728 from the Spanish Ministerio de Ciencia e Innovación (to FB), and by a post-doctoral scholarship from Obra Social "Sa Nostra", Caixa de Balears (to DAR).

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