The Construct Validity of Executive Functions in Normal Adults and in Adults with Mild Cognitive Impairment

by

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Abstract

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Effie M. Mitsis

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The construct of executive functions (EF) has remained elusive in terms of a precise operational definition. Further, little is known about the decline of EF associated with aging and mild cognitive impairment (MCI). This study examined the unitary versus multidimensional aspects of EF, and the effects of aging and MCI on EF, using a test battery comprised of classic and experimental measures of EF. Method: One hundred ninety-two participants (141 females) ranging in age from 18-90 years were administered an EF battery consisting of the Stroop Color and Word Test, Verbal and Category Fluency, Trails A & B, Wisconsin Card Sorting Test, Tower of London, Continuous Performance Test, Competing Motors Program, and Letter-Number Sequencing and Digit Span subtests of the WAIS-III. Intellectual functioning was estimated using the Vocabulary subtest of the WAIS-III. Individuals 55 years of age and over were also administered the modified Mini Mental State Examination, Wechsler Memory Scale-III Visual Reproductions, and the Selective Reminding Test. Participants were divided into three groups. Group 1 was comprised of 100 young adults (YA; mean [SD] age = 25.21[9.58] years), Group 2 of 54 older, normal adults (OA; mean [SD] age =

67.88 [7.87] years), and Group 3 of 42 individuals meeting criteria for MCI (mean [SD] age = 72.03 [8.55] years). A factor analytic approach examined the construct of EF to determine the degree to which EF, independent of IQ, is a unitary versus a multi-dimensional construct. Multivariate Analysis of Covariance was performed using each EF measure to examine the effects of age and MCI, controlling for education, IQ, and gender. Results: Both unitary and multidimensional aspects of EF were identified. Most tests of EF loaded moderately to substantially on the first un-rotated component. After rotation, 3 factors emerged which were labeled "working memory," "fluency," and "behavioral inhibition." Significant age effects were observed on many of the EF measures. MCI effects were observed only on a test of shifting mental set. Conclusion: Data indicate that EF, after controlling for IQ, is comprised of both unitary and multidimensional aspects. Data also indicate a substantial age-, but not MCI-related, decline in performance across an array of EF tests. The ability to shift mental set, or to inhibit ongoing behavior, may be impaired in individuals with MCI.

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Dedicated with love to my children

Konstantina and Christopher Mitsis

In loving Memory of

Joanna Y. Demas Antonelos

AIMS AND HYPOTHESES:

The term executive function (EF) is used to refer to a variety of loosely related cognitive functions such as self-regulation, planning, set-shifting, working memory, and inhibitory control. Anatomically, EF is believed to depend upon the integrity of the frontal lobes because patients with frontal lobe damage tend to perform poorly on neuropsychological measures of EF (Fuster, 1989; Luria, 1973). In fact, it is not uncommon to find the term "executive function deficit" used interchangeably with "frontal dysfunction" (Tranel et al., 1994).

The cognitive processes that purportedly comprise EF vary considerably across theorists and investigators (Baddeley, 1988; Fuster 1989; Goldman-Rakic, 1996; Kimberg and Farah, 1993; Lezak, 1989; Norman and Shallice, 1986; Rabbit, 1997; Stuss and Benson, 1986; Tranel et al, 1994), and the construct of EF has remained elusive in terms of a precise operational definition. In the neuropsychological literature, EF is often conceptualized as a unitary construct to describe the diverse set of functions commonly ascribed to the frontal lobes. However, reducing frontal/executive abilities to any one unitary process may not be compatible with behavioral data, and/or anatomical data derived from lesion and neuroimaging studies. Some researchers (Baddeley and Della Salla, 1998; Shallice and Burgess, 1998) argue that frontal functions are multiple and fractionated, composed of a hierarchical organization (Fuster, 1989) that represents both homogeneous and heterogenous processes (Stuss and Benson, 1986). In contrast, others (Rabbitt, 1997) suggest that EF represents a cluster of components that have neither been successfully related to each other, nor to a possible hierarchy of executive functions.

Furthermore, Rabbitt (1997) suggests that EF may represent global processes, composed of multiple sub-systems. In this view, rather than EF being separable entities that represent specific functional abilities, the multiple subsystems may be dependent upon a broad, global construct. Thus, the question remains as to whether EF may best be conceptualized as a unitary or a multi-dimensional construct, or both.

Adding to the complexity of understanding the construct of EF has been the question regarding the impact of development on EF. In children, it has been found that EF tend to mature later than most other cognitive abilities, with adult levels oftentimes not evident until well into adolescence or early adulthood (Becker, Isaac & Hynd, 1985; Case, 1992; Diamond and Taylor, 1996; Thatcher, 1992). In contrast, less is known about the impact of aging on EF in older persons. Findings suggest that an age-related decline in the neuroanatomy and neurochemistry of the brain appear to be more evident in the frontal lobes than in other cortical areas (Fuster, 1989; West, 1996), thus giving rise to the "frontal aging hypothesis" (FAH). The FAH suggests that early anatomical changes result in marked changes in EF, or, the cognitive processes historically and anatomically linked to the prefrontal cortex.

Several lines of research support the notion that elderly individuals perform poorly on neuropsychological tests of EF due to an overall general slowing of information processing speed (Salthouse, 1985). Conversely, newer research suggests that a decline in performance on tests of EF can be accounted for by deficits in performance on fluid, rather than verbal or "crystallized", intelligence tests (Duncan et al., 1995). Using a well-standardized, culture-free test of fluid intelligence, Duncan et al demonstrated that tests of frontal function are not only similar to tests of fluid intelligence in that they are measures of global and diffuse rather than of specific skills that the classic tests assume them to be, but that measures of general fluid intelligence are actually the best empirical measure of frontal/executive functioning. More specifically, Duncan et al (1995; 1996; 1997) state that frontal functions are virtually synonymous with fluid intelligence, and liken their findings to Spearman's (1927) notion of 'g'. The Duncan et al (1995) notion, while controversial, has recently garnered support from prominent researchers investigating frontal/executive functioning in aged individuals. However, the degree to which a single, 'global' EF construct versus multiple, separable EF sub-components are affected by aging, independent of IQ, has not been systematically examined.

A large body of literature suggests that disorders involving compromised frontal lobe function (e.g., Attention-deficit Hyperactivity disorder, Alzheimer's disease, frontotemporal dementia) result in EF deficits. Mild cognitive impairment (MCI) is a relatively new diagnostic entity used primarily in research settings, which refers to non-demented aged individuals with memory problems that cannot be accounted for by a medical or psychiatric condition, and in which there are no apparent changes in functional activities (Petersen et al., 1999). Of those meeting criteria for MCI, approximately half will convert to AD, whereas half will not. Conversion rates are estimated to be approximately 12% per year. Given the high rate of conversion to AD among those with MCI, some researchers suggest that MCI is early-stage AD (Bozoki et al., 2001; Hullette et al., 1998; Morris et al., 2001). Others (Petersen et al., 1999) do not agree with the hypothesis that MCI represents early-AD given the finding that the conversion rate of individuals with memory problems represent approximately 50% of cases (other researchers estimate a higher conversion rate among those with MCI to approximately 80%), while the remaining 50% of individuals with memory problems will not progress to AD.

The neuropsychological profile of MCI is not, as yet, well characterized. In view of the importance of early detection for primary prevention and treatment to delay the onset of more frank memory and cognitive impairment, the neuropsychology of MCI has recently become an important research question. Studies suggest that a decrease in episodic (verbal) memory performance has been shown to be a useful predictor in delineating whom among those with MCI will decline from those who will not (Masur et al., 1989; 1994; Petersen et al., 1999). However, distinguishing individuals with MCI from individuals whose memory deficits can be attributed to normal aging has been complicated by the fact that normal aging is associated with a decline in episodic memory. Therefore, indices of verbal episodic memory impairment alone may be insufficient in distinguishing MCI from normal age-related decline, as well as from preclinical AD. Others have found that definitions of MCI focusing primarily on memory impairment, to the exclusion of other cognitive domains, are poor predictors of dementia within a three-year follow up period (Ritchie et al., 2001 as cited in Kluger et al 2002). Thus, although memory indices are central in distinguishing who among the elderly will progress to dementia (Jacobs et al, 1995; Masur et al., 1989; 1994), memory decline alone may not be an adequate index of progression in those with MCI. An impairment in other cognitive domains such as EF may increase diagnostic accuracy and improve prognostic prediction very early on regarding who among the healthy elderly and those with MCI are likely to develop AD. Recent studies indicate that EF deficits are apparent in the early stages of AD and may be the best predictor of decline in those with memory impairments (Lafleche & Albert, 1995; Albert et al., 2001). However, the usefulness of measures of EF, while controlling for IQ, in distinguishing individuals with MCI from normal aging has not been investigated.

The aims of the present study were three-fold. The first aim was to use a factor analytic approach to examine the construct of EF in a large sample of non-impaired individuals to determine: 1) the degree to which EF, independent of IQ, is a unitary versus a multi-dimensional construct, and 2) the degree to which neuropsychological tests of EF measure this single, 'global' construct and any identifiable sub-components. It was hypothesized that a single, global EF construct will be identified, within which exist separable sub-components.

The second aim of this study was to examine the degree to which: 1) EF, as a 'global', unitary construct, independent of IQ, differs among younger (<54.11 years of age; mean age = 26) and older (≥55 years of age; mean age = 69) individuals, and 2) an age-related decline is evidenced on individual measures of EF. It was hypothesized that when both a global measure of EF, as well as individual test scores are examined, older individuals would perform more poorly than younger individuals, and that this difference would not be fully accounted for by measures of IQ.

The third aim of the present study was to further characterize the neuropsychological profile of MCI by examining whether those with MCI perform more poorly, relative to normal, age-matched controls, on tests of EF. Given the well-established finding of EF deficits in AD, along with the high rate of conversion of MCI to AD, it was hypothesized that individuals meeting the present study's criteria for MCI (see Table 2) would perform poorly as compared to age-matched controls on EF tasks assessing working memory, response/behavioral inhibition, and semantic fluency.

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INTRODUCTION

Executive functioning refers to a variety of related cognitive processes such as planning, set-shifting, working memory, self-regulation of goal-directed behavior, and inhibitory control, which are believed to be subserved by circuits involving the prefrontal cortical regions of the brain. Executive functions are believed to depend upon the integrity of the frontal lobes because neuroanatomical (Fuster, 2000; Petrides, 1994; Goldman-Rakic, 1987) and behavioral studies (Anderson et al., 1991; Miller, 1992) have indicated that patients with frontal lobe damage tend to perform poorly on tests that purportedly assess these various functions. In fact, this notion has been supported by a host of studies, using both classic EF paper and pencil tests, as well as computerized versions (e.g., the Cambridge Neuropsychological Test Automated Battery [CANTAB]; Robbins et al., 1994) that purportedly tap into these various domains. However, these findings are complicated by the fact that some 'frontal' patients perform well on tests of EF (Shallice and Burgess, 1991), whereas patients with non-frontal lesions may perform poorly on these very same tests (Anderson et al., 1991; Reitan and Wolfson, 1994).

Recent neuroimaging studies have supported what behavioral and lesion studies have suggested by demonstrating that "executive functioning" is primarily associated with frontal activation (D'Esposito et al., 1995; D'Esposito et al., 1999; D'Esposito et al., 2000; Leyton et al., 2001; Petrides, 1994; Rypma and D'Esposito, 1999; Siever et al, 1999; Smith & Jonides, 1999; Wagner et al., 2001). In support of the notion that EF deficits are associated with frontal lobe sequella, studies have reported reduced activity in the prefrontal cortex (PFC) of adult psychiatric patients (Siever et al., 1999), adolescents with AD/HD (Rubia et al., 1999), and in violent offenders (Bergvall et al., 2001; for a review see Brower and Price, 2001) during performance on EF tasks.

FRONTAL LOBES AND EXECUTIVE FUNCTION

There is an intimate relationship between the types of cognitive processes subsumed under the term 'executive functions' and the prefrontal region of the brain. In most studies, discussion of an EF deficit is accompanied by a discussion of PFC dysfunction, thus linking a neuropsychological term, used to describe a variety of cognitive processes, with an anatomical term that describes a particular region of the brain (Tranel et al., 1994). Some of the wide-ranging functions subsumed under the rubric of EF have been linked to one or another region of the PFC, such as the dorsolateral PFC or the orbitofrontal region. However, this distinction does not account for the PFC's intricate neural connectivity with other regions of the brain, in that it sends efferent, and receives an abundance of afferent, projections.

Many have theorized that the PFC provides the neural substrate of complex mental processes such as abstract reasoning, foresight, planning capacity, self-awareness, empathy, and the modulation of emotion (Benton, 1991 in Levin, Eisenberg and Benton). In order to better understand the notion of EF, it is important to discuss the history of the emergence of the term through its association with frontal lobe injury.

Emergence of the term "executive function":

Interest in the higher cognitive abilities of the human brain can be traced back many centuries. By the early part of the 17th century the frontal lobes were defined in terms of three prominences. Two centuries of controversy followed regarding two influential hypotheses of the time: one espousing localization of function and the other suggesting mass action of all brain regions for any behavior. However, by the late 19th century, the observation that brain injured individuals showed discrete deficits lead to a surge of animal experimentation and clinical observation trying to get to the root of localization of function and the role of the frontal lobes. Consistent correlations between defects and the locus of the lesions could not be established.

Case reports of the time abounded with descriptions of asymptomatic patients with extensive frontal lesions, thus leading to the notion that the prefrontal region was a "silent area" of no functional significance (Benton, 1991; Tranel et al., 1994). Implications of frontal lobe function were finally appreciated following the famous 19th century crowbar case. A young man by the name of Phineas Gage had survived an injury in which a tamping iron had pierced his skull, entering through his left frontal lobe, emerging from the right frontal bone near the sagittal suture, and leaving a circular opening of about 3.5 inches in diameter. This accident resulted in destruction of Gage's left frontal lobe and anterior temporal pole (Benton, 1991). A follow-up report on this patient by Harlow in 1868 described Gage's status until his death 13 years after the accident. Phineas Gage did not appear to have suffered intellectual impairment because his memory and temporal orientation were intact, and he was able to work again after his injury. However, about a month after his injury he exhibited a marked change in personality. Where he had once been an honest, soft-spoken, hard-working individual, he had become obstinate and profane, and often exhibited poor judgment. This distinctive type of personality change would later be associated with frontal lobe disease.

During the golden age of cerebral localization (1870-1890), the delineation of functions of the frontal lobes became an important research focus via animal experimentation using ablation and excision techniques (Benton, 1991). Experimental ablation of dog and monkey PFC revealed significant changes in the animal's behavior with no apparent changes in sensory or motor function. Ablation resulted in animals that were apathetic, uninterested in their surroundings, inattentive, and distractible. In addition, they exhibited behavior similar to impulsivity, and when frustrated, they were given to aggressiveness. These features corresponded to clinical findings in humans who had sustained frontal damage, and soon this constellation of symptoms became known as the "frontal lobe syndrome". Adding to the further characterization of this syndrome, Bianchi in the late 1880s made the observation that the frontal lobe changes in these patients reflected disintegration of the total personality rather than a loss of 'general intelligence' or a specific ability. During this same time, Hughlings Jackson (1884) suggested that there were 'higher centers' that were responsible for controlling the actions of 'lower centers'. This notion of higher and lower centers may have been a precursor to present day notions of the PFC's role in higher order cognition as a control mechanism for lower order cognitive function (e.g., Luria, 1973; Baddeley and Hitch, 1974).

Ferrier, in 1876, was intrigued by the outcome of experiments in which monkeys were subjected to near-total frontal lobe resections. As with Phineas Gage, the monkeys appeared to be remarkably free of basic motor or sensory defects, but Ferrier noted that there was a very distinctive alteration in the animals' character and behavior. The monkeys appeared to have lost the faculty of attentive behavior and intelligent observation, without having lost their 'intelligence' per se. Ferrier's idea of 'intelligent observation' can be considered a precursor to modern notions of abstract reasoning, insight, and cognitive flexibility (Tranel et al., 1994).

By the 1930's, further animal experimentation showed that animals with prefrontal lesions could not perform delayed response tasks, which required the holding in mind of a particular stimulus or environmental event over a delay of seconds or minutes. The performance failure was considered to be the loss of the ability to maintain a 'mental set', an early description of an EF. The capacity to control or integrate behavior is another early description of an EF; the loss of this capacity, along with disturbances of affect and personality, was linked to frontal lobe injury (Feuchtwanger, 1923 as cited in Benton, 1991). Goldstein in the 1920's further added to the notion of EF with his concept of the 'abstract attitude'. The abstract attitude was defined as capacities such as abstract reasoning, initiative, foresight, resistance to suggestion, self-awareness, and behavioral and cognitive flexibility (Tranel et al., 1994). Although the term abstract attitude lost popularity, the features that comprised its core elements are now known as executive functions.

By the mid-20th century, distractibility, lack of cognitive flexibility, and perseveration (Ackerly and Benton, 1948) were added to the collective behavioral/cognitive features of EF. A large body of modern research (1970-present) has further conceptualized the notion of EF, and investigators have proposed a number of different models of the functions of the PFC. Prominent among these are the concepts of frontal lobe/executive function proposed by Luria (1973), Fuster (1989), Lezak (1983;

1994), Goldman-Rakic (1996), Stuss and Benson (1986), Norman and Shallice (1986), and Baddeley and Hitch (1974).

MODELS OF EXECUTIVE FUNCTION

Luria's model:

Adhering to the notion that the PFC has a rich system of afferent and efferent connections with nearly every other principal area of the cortex, Luria (1973) stated that the frontal lobes are a superstructure above all other parts of the cerebral cortex and that their universal function is the general regulation of behavior. Relying on extensive clinical findings, Luria ascribed the role of the frontal lobes to the programming, regulation and verification of conscious activity (p. 93). According to Luria, the frontal lobes have an important role in the regulation of voluntary attention and the ability to form stable plans and intentions that serve to control conscious behavior. He stated that frontal lesions lead to a paucity of action and a disturbance in goal-directed behavior. Luria further distinguished between patterns of disturbances based on location of frontal lesions. The lateral zones, he posited, lead to disturbances of the organization of movements and actions, which are dependent upon speech for their regulation. On the other hand, the orbital medial zones of the frontal lobes have a different functional organization than the lateral zones. Lesions to orbital medial areas lead to generalized disinhibition and changes in affect. For example, lesions to orbital cortex result in changes in personality and character, such as violent emotional outbursts and loss of self-control. However, intellect appears to remain potentially intact with lesions to the orbital zone whereas lesions to the lateral zone result in "adynamia of thought" (p. 223). Yet, despite relatively intact intellect in individuals with orbital medial lesions, the increased disinhibition and impulsivity leads to an inability to plan and organize intellectual activity.

Lezak's model:

According to Lezak (1995), EF can be conceptualized as having four components: 1) volition, 2) planning, 3) purposive, goal-directed action, and 4) effective performance, all of which are necessary for appropriate and effective behavior. Volition is the capacity to form an intention. Motivation is a necessary precondition for volition. People who lack volition cannot think of anything to do and may be either apathetic or, on the other hand, unable to initiate activities despite being able to do so. Planning involves the identification and organization of the steps needed to carry out an intention or achieve a goal. In order to plan, one must be able to conceptualize changes from the present situation/circumstance, adjust ones behavior to the intended action, and be able to take the abstract attitude. The planner must be able to think of alternatives, make choices, and weigh different options or ideas. Impulse control, the ability to sustain attention, and intact memory function are all necessary for effective planning. Purposive action is the translation of an intention or plan into activity, which requires the individual to initiate, maintain, switch, and stop sequences of complex behavior. Disturbances in the programming of activity can disrupt the carrying out of plans regardless of motivation, knowledge, or ability to perform the activity. People who have trouble programming an activity may display dissociation between verbalized intentions and plans and their actions (Lezak, 1994). This deficit in self-regulation is often observed clinically during testing situations when a patient will do one thing while saying or intending to do another. Finally, effective performance involves the ability to monitor, self-correct, and regulate how one will respond. Thus, the individual must be aware of the goal and of the extent to which a particular pattern of action is approximating that goal; this depends on self-monitoring, self-correcting, and the ability to regulate one's behavior in order to achieve effective performance (Lezak, 1995).

In Lezak's discussion of the types of behavioral deficits that are associated with damage to the frontal lobes, she provides an outline of EF disturbances. For example, she indicates problems of starting (e.g., loss of initiative), perseveration (e.g., difficulties making mental or behavioral shifts), problems in stopping (e.g., disinhibition, impulsivity), deficient self-awareness (e.g., an inability to comprehend one's role in a social situation or to appreciate one's errors in performance), and concrete attitude (e.g., the inability to understand the abstract nature of stimuli and situations, and to plan and maintain goal-directed behavior).

Fuster's temporal processing model:

Fuster (1999) suggests that the frontal cortex is the highest stage of a hierarchy of neural structures dedicated to the representation and execution of action. At the base of this hierarchy is the primary motor cortex, which is in charge of the execution of skeletal movements. Above this area is the pre-motor cortex, serving more complex, goal-oriented movements. This area is also involved in speech. At the summit of this hierarchy is the PFC, which represents the broad schemata of action in the skeletal and speech domains and, in addition, is critically involved in the enactment of these schemata or plans. Because of these functions, the PFC is essential for the temporal organization of behavior and spoken language. Thus, the PFC is motor cortex of the highest order in that it supports the cognitive functions that coordinate the execution of the most elaborate and novel actions of the individual (Fuster, 1999). According to Fuster, this role of the PFC, more commonly referred to as EF, is essential for the sequencing of new and complex behavior, including speech and logical reasoning.

For behavior to become temporally organized in the execution of a planned action, temporal integration is needed. According to Fuster (1989), cross-temporal mediation is carried out by three sub-functions which are thought to be three basic cognitive functions of the PFC: 1) short term motor memory or preparatory set for forthcoming action, 2) short-term perceptual memory, better known as working memory, for retention of sensory information on which that action is to be based, and 3) inhibitory control of interference, namely, a function to suppress all internal or external information that could interfere with the action at hand. According to Fuster (1989), preparatory set and working memory are based in the dorsolateral cortex and inhibitory control and distractibility in the orbital cortex. These functions cooperate with one another to ensure that complex sequences of goal-directed behavior are accurately executed. This functional cooperation engages other cerebral structures connected with the PFC. Fuster's theory has yet to be examined for practical utility in neuropsychological studies investigating EF in humans.

Goldman-Rakic's model:

Based on a large and seminal body of work in non-human primates, Goldman-Rakic (1996) suggests that higher cognitive processes involve different prefrontal subdivisions, which represent different informational domains rather than different processes. As such, she suggests that more than one working memory domain exists in the PFC. Although the PFC has a pre-eminent role in working memory and higher cognitive functions, it does so as part of an integrated network of areas, each dedicated to carrying out specialized functions. Each working memory domain is embedded in, and supported by, a distinct and independent network of cortical areas; thus, networks are functionally integrated by domain. For example, the prefrontal areas engaged in 'spatial' working memory are interconnected with portions of posterior parietal cortex, while the 'feature' working memory areas of the inferior PFC are interconnected with area TE in the temporal lobe (Cavada & Goldman-Rakic, 1989; Carmichael & Price 1995; Goldman-Rakic, 1996). A network is comprised of sensory association, premotor, and limbic areas. All connections within a network are reciprocal. Therefore, this model of PFC network organization contrasts with other theories of prefrontal organization, which distribute attention, affect, memory, and motor action among the different cytoarchitectonic regions of the PFC (for e.g., see Robbins, 1996). The multiple domain model suggested by Goldman-Rakic distributes these functions among the cortical areas within networks defined by informational domain.

This model provides an alternative model to Baddeley (1986; see below). For example, Baddeley (1986; 1996) and Robbins (1996) separately suggested that the dissociable aspects of EF are mediated by distinct neural systems that engage different regions within the PFC. According to Goldman-Rakic (1996), Baddeley's (1986) notion of central executive processing may be the result of the interaction of multiple independent information processing modules each with its own sensory, mnemonic, and motor control features. This model views that the central executive may be composed of multiple segregated special purpose processing domains rather than one central processor served by slave systems converging to a central processor; and that each specialized domain consists of local and extrinsic networks with sensory, mnemonic, motor, and motivational control elements (Goldman-Rakic, 1987; Goldman-Rakic, 1996). According to Goldman-Rakic, this process-oriented view explains Baddeley's (1988) concept of the dysexecutive syndrome - disorganization, perseveration, and distractibility - as a default in one or more independent working memory domains. Thus, this model views the highest level of cognition as involving the co-activation of multiple working memory domains within the PFC, along with associated cortical networks which results in a parallel processing architecture (Goldman-Rakic, 1996).

Stuss and Benson's model:

Stuss and Benson (1986) divide the functions of the frontal lobes into two groups. One group is concerned with sequencing behaviors, forming mental sets, and integrating various behaviors (Levine, Stuss, and Milberg, 1995). The other group is concerned more with primitive processes such as drive, motivation, and will. The first group is associated with dorsolateral PFC activation whereas the latter group is associated with ventromedial PFC activation. These behaviors are at the top of a hierarchy of behaviors that control a person's interactions with the world. Stuss et al (1995) have gone beyond this simple characterization of the role of the PFC and have distinguished among a large set of top-down attentional processes that may be subserved by PFC. These independent attentional processes have been shown to be selectively impaired by prefrontal cortical lesions, and involve input from posterior cortical regions (Stuss, December 2000; personal communication).

Norman and Shallice's model:

Norman and Shallice (1986) proposed that two basic control mechanisms determine how we monitor our activities. One mechanism is called the contention scheduler, which operates via automatic and direct priming of stored knowledge either by stimuli in the environment or conceptual thought. The second mechanism is called the Supervisory Attentional System (SAS) which reflects conscious awareness, and works within working memory, or internal knowledge states that determines an individual's impending action despite contrary or absent environmental stimuli (Norman & Shallice, 1988). This stored knowledge reaches consciousness and can override the automatic contention scheduling mechanism. Grafman (1995) provides an excellent example regarding the operations of the two control mechanisms. He states: if the rules governing social behavior require that a visitor not answer a ringing phone in the home of someone they are visiting (SAS; conscious awareness), the activation of those rules should override the automatic contention scheduler which might signal the person to answer a ringing phone. The contention scheduler is automatic, implicit, and easily activated. The SAS is controlled, explicit, but also easily activated. The homeostasis between the two attentional control systems is critical to maintaining conventional behavioral interactions with the environment. The dividing of the attention system between automatic contention scheduling and controlled supervisory mechanisms accounted for attention and action failures of patients with PFC lesions who have a tendency to respond to the automatic demands of the environment, as seen in impulsive and rule-breaking behaviors. It has been postulated that the SAS interacts with anterior brain systems (Norman & Shallice, 1988; Baddeley, 1988).

Baddeley and Hitch's central executive model:

Baddeley and Hitch (1974) proposed a model of working memory in which two slave systems, the Phonological Loop (PL), which is specialized for language, and the Visuospatial Sketch Pad (VSP), which is specialized for spatial material, is held together by an attentional system termed the central executive. The central executive is the "overall controller, organiser, planner and allocator of resources" (Wilson et al., 1996, p.20). The slave systems have thus far been further fractionated into subcomponents (Baddeley, 1996). In this model, lower level tasks are handled by the 'slave' systems, but the central executive is an overarching control structure, similar to the SAS of Norman and Shallice (1986). In essence, the central executive's function was defined in terms of those aspects of performance that could not be attributed to either the PL or the VSP. Hence, the role of the central executive has been criticized as having been defined by default and being homoncular in nature (Parkin, 1998).

Baddeley (1998), in response to Parkin's (1998) criticism, states that the central executive should by no means be considered dependent upon a single anatomical location (Baddeley, 1996), nor is it to be, in any way, considered a unitary entity (Baddeley, 1998; Shallice and Burgess, 1998). According to Baddeley (1998), given the vastness of the frontal lobes, executive processes are likely to involve links between different parts of the brain, and are thus unlikely to be exclusively associated with a frontal location. As a result, patients may have executive deficits without evidence of frontal damage, or patients may have frontal lesions without concomitant executive deficits. In fact, Baddeley (1996) proposed the concept of a 'dysexecutive syndrome' to separate function from location, and to identify any fraction-able subcomponents of the central executive.

Furthermore, he has subsequently postulated other executive processes, which involve the focusing of attention, and attention switching, together with a system concerned with the control of long-term memory (Baddeley, 1996).

In the early stages of theoretical development, both the central executive and the SAS had a unitary flavor, without including distinct sub-components (Rabbitt, 1997). In support of this notion, recent conceptions of EF suggest that there may be some unifying mechanism that may characterize the nature of deficits in frontal lobe patients or functions of the frontal lobes (Duncan, Emslie, Williams, Johnson, & Freer, 1996; Duncan et al., 1997; Engle, Kane, & Tuholski, 1999; Kimberg & Farah, 1993; as cited in Miyake and Shah, 1999). According to Miyake and Shah (1999), each of these theoretical viewpoints, however, differ in the mechanism by which EF operate. Specifically, Duncan et al (1996; 1997) state that frontal functions are synonymous with fluid intelligence, or Spearman's (1927) notion of 'g'. Kimberg and Farah (1993), using computational modeling, suggested that the various functions associated with the frontal lobes may be managed by separate working memory systems, each of which is dedicated to a single, situation-specific function. In this view, any one of the working memory systems might be damaged without affecting the other systems, resulting in the frequent finding of lack of an association between performance deficits and lesions (Rabbitt, 1997).

Further evidence for the non-unitary nature of frontal lobe function or EF is based upon clinical observations (Baddeley, 1996 as cited in Miyake and Shah, 1999). For example, some patients may fail on the Wisconsin Card Sorting test (WCST), but not on the Tower of London (TOL), tests that are purported to tap in to similar functional abilities. Other patients may show the opposite pattern (e.g., fail the TOL but not the WCST), suggesting that EF may not be completely unitary (e.g., Godefroy, Cabaret, Petit-Chenal, Pruvo, & Rousseaux, 1999; Shallice, 1988). However, the conflicting results found in many studies may be due to the task impurity of many tests of EF (Weiskrantz, 1992; Rabbitt, 1997). Other studies raising doubts about the unitary nature of EF have been those that have examined a wide range of individuals including normal young adults (Lehto, 1996), normal elderly adults (Lowe and Rabbitt, 1997; Robbins et al., 1998), brain damaged adults (Burgess, 1997; Burgess, Alderman, Evans, Emslie, & Wilson, 1998; Duncan et al., 1997), and children with head injury (Levin et al., 1996) and ADHD (Schachar, Tannock & Logan, 1993). These studies are similar in the sense that they each used a battery of widely used executive tasks and examined how well these tasks correlated with one another by performing correlation-regression analyses and exploratory factor analysis. A highly consistent finding across these studies is that the intercorrelations among different executive tasks are low and, in many cases, are not statistically significant. In addition, factor analysis yields multiple separable factors (rather than a unitary factor) in studies that used a battery of executive tasks. Thus, based on findings from studies employing a factor analytic approach, it is postulated that the functions of the frontal lobes consist of multiple components. However, researchers that have employed the factor analytic approach often have difficulty in interpreting what the factors derived really represent. In fact, interpretation of derived factors is, for the most part, arbitrary and post-hoc.

EXECUTIVE FUNCTION: UNITARY OR MULTIDIMENSIONAL?

While an extensive imaging literature suggests that EF primarily involves the frontal lobes, recent findings suggest that adequate executive functioning involves multiple connections between both frontal and posterior regions of the brain (Carpenter et al., 2000; Jonides et al, 1999). Moreover, the frontal cortex is composed of a heterogeneous cellular structure in that a number of prefrontal regions are differentiated from each other on architectonic grounds (Benton, 1991; Damasio, 1991). Thus, it is possible that several regions of the frontal cortex are involved in distinct types of processes that operate in concert with posterior regions of the brain (Carpenter et al., 2000). However, despite the architectonics of the frontal cortex and the recent neuroimaging findings, 'executive functioning' is generally conceptualized in many studies as processes that operate in a unitary manner, with adequate functioning very much dependent on the integrity of the frontal lobes of the brain (Duncan et al, 1996; Duncan et al., 1997; Engle et al., 1999; Kimberg and Farah, 1993).

The notion of EF as a unitary entity suggests that the various executive processes operate in a global manner, and become disrupted as a result of some form of frontal pathology (Duncan et al, 1996; Duncan et al., 1997; Engle et al., 1999; Giancola et al, 1996; Kimberg and Farah, 1993 as cited in Miyake et al., 1999). Others have proposed that the executive system itself is "fractionated" (Baddeley and Della Salla, 1998; Robbins, 1996), with tests of EF measuring different functional components (Baddeley and Della Sala, 1998; Burgess et al, 1998). A combination of both theoretical perspectives might suggest that executive functions are composed of a single component that serves a common, overall function (e.g., a global central executive or an attentional allocator) and is, to a degree, responsible for the activity of the various cognitive functions. However, as task complexity increases, or as the various aspects of EF are mobilized, separable, distinct entities emerge. Were this the case, then analysis of performance on a variety of EF tests may reveal the presence of both unitary and multidimensional components (Duncan et al., 1996; Duncan et al., 1997; Engle et al., 1999; Kimberg and Farah, 1993; Mitsis and Halperin, 2001; Miyake et al., 2000). In fact, nearly a quarter century ago in his review of frontal lobe function, Teuber (1972) suggested that EF may be best conceptualized as comprising both unitary and diverse functions. To date, however, the field is lacking in a comprehensive and compelling theory of EF. For instance, a remaining source of controversy in the neuropsychological literature is the question regarding the extent to which the different functions often attributed to the frontal lobes, or to the central executive (or, to the SAS for that matter), can be considered unitary in the sense that they are reflections of the same underlying mechanism or ability. According to Stuss and Alexander (2000), a unitary EF does not exist. Rather, distinct processes related to the frontal lobes can be differentiated, which converge on a general concept of control functions (Rabbitt, 1997). Baddeley (1988; 1996) proposes a fractionation of executive processes within the context of working memory and Goldman-Rakic (1996) proposes that multiple working memory subdomains exist within the PFC.

VALIDITY OF EXECUTIVE FUNCTION TESTS

Another important issue when interpreting the findings of EF studies is related to poorly established validity (Phillips, 1997; Rabbitt, 1997; Reitan and Wolfson, 1994), low reliability (Denckla, 1996; Rabbitt, 1997), and the concept of task impurity (Weiskrantz, 1992). Many popular EF tests have been validated solely by the criterion of being sensitive to frontal lobe damage in *some* people. Neuropsychological tests that are known to be sensitive to frontal lobe damage have been used to measure EF. However, establishing the validity of tests of EF on the basis of their sensitivity to frontal lobe lesions is somewhat circular (Phillips, 1997). These tests are used to assess EF because individuals with executive dysfunction have been found to be impaired on them. Thus, tests of EF are deemed to be such because they are sensitive to frontal lobe damage in some people, and not because they have been operationalized to assess the theoretical concept of EF and the group of cognitive processes that purportedly comprise EF (Bryan and Luszcz, 2000).

The major concern regarding the validity of executive tasks is that it has been difficult to establish the purity of these tasks. Furthermore, it has been difficult to establish that different executive tests assess the different functional components of EF (e.g., inhibition, planning abilities, or working memory), or for that matter, to differentiate between executive and non-executive tasks (Rabbitt, 1997). Rabbitt suggests that EF represent a cluster of components that have neither been successfully related to each other, nor to a hierarchy of EF (e.g., Fuster's theory, 1989). It is expected that tasks which are purported to assess similar EF, such as planning or inhibition, would be strongly associated with each other, whereas tasks assessing different executive components would be less strongly associated. However, differentiation among the different EF components is not often found (Rabbitt, 1997). For example, Rabbitt reports a failure to find a difference in inhibition between a variety of logically identical, but superficially dissimilar, Stroop-like tasks among healthy older adults.

Furthermore, there is the problem of cognitive congruence, which is the finding that virtually any cognitive task correlates positively with performance on any other task. Some have suggested that executive tasks may reflect processes common with Spearman's (1927) concept of 'g' (Duncan et al., 1995). Rabbitt (1997) found that, among healthy older adults, executive tasks did not load on a common factor and the association between executive task performances was entirely accounted for by a common loading with intelligence. However, when examining the contributions of age, speed of processing, and fluid intelligence on tasks assessing EF, Lowe and Rabbitt (1997) found that age-related variance on executive tasks remained after controlling for speed and intelligence. In a recent review, Burgess (1997) concluded that tasks of EF, in general, share greater relationships with each other than can be explained by cognitive congruence.

Rabbitt (1997) suggests that some of the difficulty associated with differentiating between executive tasks, and between executive and non-executive tasks, could be that all executive tasks require similar processes for their successful performance, or that they all rely on a common pool of cognitive resources. Thus, executive tasks may be impure because they draw upon a variety of different cognitive processes. In fact, it may be impossible to obtain a pure test of EF because the theoretical construct of EF, and thus all tests which measure it, entails the simultaneous management of a variety of different cognitive functions (Rabbitt, 1997).

Construct validity of EF tests:

Many widely used measures of EF have questionable construct validity (e.g., WCST and the TOL). Specifically, the unclarity of the underlying abilities that are tapped by executive tasks is reflected in the proliferation of terms and concepts used to characterize different EF tasks. For example, different researchers may refer to the WCST as a measure of "set shifting", "inhibition", "flexibility", or "problem solving". These terms have not been independently tested. Another example involves the term "inhibition", the ability to ignore and withhold habitual or over-practiced responses and to attend to goal-related stimuli, which has classically been demonstrated with the interference condition of the Stroop. An extensive literature has supported the notion that inhibition is a functional property that is gradually lost in old age (West, 1996). This notion is supported by studies indicating that older individuals perform more poorly, relative to younger control groups, on Stroop-type tasks in which they are required to inhibit some practiced response in order to make another (West, 1996). Yet, as mentioned above, some researchers have been unable to find any differences in inhibition between a wide variety of logically identical, but superficially dissimilar Stroop-like tasks (Rabbitt, 1997) across similar groups of individuals. In other words, these researchers were not able to indicate that the term "inhibition" has empirically demonstrable construct validity, even when assessed by tasks considered to be operational definitions of the term. Hebb (1945) very early on expressed wariness about vague definitions of frontal functions.

The concept of "switching", or shifting, of mental set is commonly believed to be a distinct EF involving intact frontal lobe functioning. To determine whether "switching" of mental set had any demonstrable validity as a construct identifying a particular kind of functional operation necessary to carry out a particular kind of task demand, Lowe and Rabbit (1997) found that there was no evidence that switching of attention between different categories of symbols involves a functional mechanism that is selectively damaged in a group of healthy elderly volunteers, causing them to perform poorly on similar tasks. Thus, attentional switching was not validated as a functional construct in that study.

The problems with the construct validity of tests of EF may be a reflection of "task impurity" (Weiskrantz, 1992). Tasks that are often used to assess EF are 'impure' in the sense that they may also make demands on a variety of other cognitive skills or functions that are supported by brain structures that are independent of the frontal lobes. It is common in studies to use only a single performance parameter, such as reaction time or percentage correct, as the only comparison between groups (e.g., older versus younger; more versus less intelligent). This approach may be restrictive in that single performance parameters may represent the pooled outcomes of many distinct functional processes (Rabbitt, 1997).

In summary, EF tasks have mainly been validated to a criterion: their sensitivity to frontal lobe lesions. This is problematic, given the large variation between frontal lobe patients with regard to their performance on EF tasks (Anderson et al., 1991; Reitan & Wolfson, 1994; Shallice & Burgess, 1991). Furthermore, it is not accepted by everyone that EF resides in the frontal lobes (Reitan & Wolfson, 1994). The notion of frontal lobe involvement in EF tasks is circular: patients with frontal lobe lesions have been found to perform poorly on tests thought to measure EF, therefore EF is located in the frontal lobes; hence, any test on which frontal patients perform poorly on is an executive test. In addition, construct validity is problematic given that frontal tests have been so widely accepted as a measure of EF when there is a paucity of empirical evidence regarding the cognitive processes involved in these tasks. Validation is problematic because it is impossible for a single test score to estimate 'pure' EF without involvement of other aspects of cognition (Phillips, 1997). This may be because EF manifests itself by operating on other cognitive processes (Rabbitt, 1997), which raises the possibility that EF tests may also involve linguistic or visual-spatial processing, short- or long-term memory, and motor or verbal responses. If any of these functions fail, there may be an effect on test performance. Thus, there could be many possible reasons for poor performance on an executive test (Phillips, 1997; in Rabbit, 1997).

Many of the 'classic' tests of EF have questionable validity. For example, tasks such as the WCST, considered to be the quintessential test of EF, or the TOL, which are purported to tap functions that are linked to the PFC, may be tapping either multiple functions of the PFC, or non-executive components that are not specific to the PFC. Thus, these tests, which are often used in the assessment of frontal/executive functioning, may be poor at differentiating among different types of PFC deficits, or among PFC deficits from non-PFC deficits (Pennington & Ozonoff, 1996). Hence, most classic tests of EF have questionable validity (Rabbitt, 1997) and may be impure (Weiskrantz, 1992) in the sense that they are tapping into multiple domains and recruiting regions outside of the PFC. Thus, questions remain regarding what EF really represents. Are EF related exclusively to the PFC, do they involve interrelations with other cortical areas via reciprocal circuits or dynamic processes, or are they distinct in the sense that they measure separable and distinct functional 'abilities' such as inhibition, planning ability, and/or working memory.

EXECUTIVE FUNCTION AND AGING

Development of EF in children:

A feature of EF is their protracted developmental progression in comparison with other cognitive functions. In addition, the protracted development of EF parallels the prolonged pattern of neurodevelopment of the prefrontal regions of the brain (Case, 1992). Using the theoretical approaches of both Stuss (1992) and Thatcher (1992), Case (1992) correlated functional and cognitive changes (Stuss, 1992) with physiological changes (Thatcher, 1992) occurring in the frontal lobes of children. Case suggested that between the ages of 1.5 and 5 years, a sequence of changes takes place in children's behavior that indicates a fundamental reorganization of their attentional and executive processes.

The development of attentional control, future-oriented intentional problem solving, and self-regulation of emotion and behavior can be observed beginning in infancy and continuing through the preschool and school-age years (Welsh & Pennington, 1988). Developmental studies of children through adolescence demonstrate a time-related course of development, and an age-related improvement in performance, for specific subdomains of EF. These subdomains include inhibitory control (Passler et al., 1985), the ability to attend to two things at the same time while exercising inhibitory control (Diamond & Taylor, 1996), as well as planning and problem-solving (Levin et al., 1991; Welsh et al., 1991). Furthermore, in the Welsh et al (1991) study, EF was found to be independent of IQ. Specifically, these researchers tested participants between the ages of 3 and 28 on tests of EF. Their findings indicated that adult level of performance on tests of EF seemed to be reached in three stages: 1) simple planning and organized visual search by 3 years of age; 2) set maintenance, hypotheses testing, and impulse control by age 10; 3) complex planning, motor sequencing, and verbal fluency during adolescence. Temporal ordering (Milner, Petrides, & Smith, 1985) follows a developmental pattern from age 6 to 12 (Becker et al., 1987). By the time children are 3 to 6 years of age, they may be employing strategies to aid in their performance on tasks of EF (Mischel & Mischel, 1983 as cited in Welsh).

Control of motor responses is reportedly impaired after frontal lobe lesions in adults (Luria, 1973). An aspect studied in children, the verbal regulation of motor responses, moves in a developmental sequence from overt to internal control, primarily during the ages of 2 to 5 years. Children have been found to use covert speech to direct action effectively at around age 5 (Conrad, 1971), with older children reverting to overt regulation when confronted with difficult tasks.

Among the more complex motor skills such as inhibition, the most significant development in motor task abilities occurs between the ages of 6 and 8, with some EF still not mastered by age 12 (Becker, Isaac & Hynd, 1987). Interestingly, these authors observed the classic frontal lobe sign of dissociation between correct verbalization and incorrect action as described by Luria (1973). While children of all ages could verbalize task demands, younger children were impaired in the inhibition of inappropriate responses.

The development of attentional functions has shown that the ability to attend selectively to and disregard distractions follows a developmental sequence from ages 5 to 9. Passler, Isaac, and Hynd (1985) administered several attentional tasks of increasing difficulty to children who ranged in age from 6 to 12 years. Among tests requiring selective attention, some were mastered between the 6th and the 8th year, but complete mastery of all skills was not obtained in all children even by age 12. When using the WCST, the prototypical test of EF, Chelune et al (1986) found that among children with average IQ, the development of problem-solving strategies, the capacity to shift set and suppress inappropriate responding, and the ability to selectively attend to relevant stimuli without distraction are developmental tasks that appear to reach adult levels of maturity by the age of 10. Children between the ages of 4 to 13 perform, overall, better on 'posterior' tests than on frontal tests. Errors on frontal executive tests diminish over time between the ages of 6 and 10, with adolescents performing like normal adults (as cited in Stuss, 1992).

Decline of EF in adults:

A large body of research suggests that EF decline with age. Several theories (West, 1996; Salthouse, 1985; Duncan et al., 1995) have attempted to account for the decline in performance on tests of EF in adults. Among these theories are the frontal aging hypothesis (FAH; West, 1996), a decline in speed of information processing (Salthouse, 1985), and the more recent approach by Duncan et al (1995) which suggests that a decline in fluid intelligence accounts for the poor performance by adults on tests of

EF. More specifically, Duncan et al propose that fluid intelligence is virtually synonymous with frontal/executive functioning.

The FAH:

The findings that older adults, relative to younger adults, perform poorly on measures of frontal lobe function, while performing comparably on tasks of nonfrontal function (Ardila & Rosselli, 1989; Whelihan & Lesher, 1985) has lead to a proliferation of research suggesting that the cognitive processes supported by the frontal lobes, or the PFC, are among the first to decline with increasing age (Daigneault, et al., 1992; Dempster, 1992). This notion appears to be supported by both structural and functional changes in the PFC. Specifically, the structural and functional changes noted to occur earlier in the PFC relative to other brain regions are a shrinkage of cells (Haug and Eggers, 1991), a reduction in the number of synapses during the aging process (Huttenlocher, 1979), a reduction in the number of receptor sites for the neurochemical dopamine in both animals (Goldman-Rakic & Brown, 1981) and human adults (de Keyser et al., 1990), and hypofrontality as characterized by a decline in rCBF using PET (Gur et al., 1987). West (1996) reports that the presence of senile plaques in greater concentrations within the frontal lobes in healthy nonhuman primates supports the notion that the frontal cortex is more sensitive to the effects of aging than other cortical regions (Dempster, 1992). Yet, the presence of senile plaques does not appear to be related to cognitive change (Berg et al., 1993 as cited in Greenwood, 2000). Furthermore, while the elderly are impaired in working memory, a function primarily mediated by the PFC, they are also significantly impaired in visuospatial attention, face recognition, and repetition priming, all of which are not dependent upon the PFC (Greenwood, 2000).

The FAH predicts that some aspects of the physical integrity of the frontal lobes deteriorate selectively in aging. However, Greenwood's review of the literature found that although there is evidence of compromised frontal integrity in the form of reduced volume and metabolism, these measures are altered in temporal and parietal lobes as well. Although volume loss may be greater in certain frontal areas, not all studies report such a finding (Jermigan et al., 1991; Raz, 1996). Furthermore, the significance of volume reduction in aging is uncertain, as it does not correlate well with age-sensitive functional decline (Raz et al., 1998). In addition, prefrontal, parietal, and temporal regions all exhibit resting hypo-metabolism in the elderly (Azari et al., 1992; Martin et al., 1991). Further conflicting with the FAH are findings that the elderly experience reduced efficiency in prestriate visual areas, leading to greater processing dependence on regions outside visual areas (e.g., area 37 and frontal areas). Imaging studies in humans (Grady et al., 1998) and in monkeys (Bachevalier et al, 1991) support this view. As monkeys age, memory is spared but spatial processing is impaired before other functions. There appears to be selective effects of aging on extrastriate areas (Rapp et al., 1997). Thus, declining extrastriate function leads to increased temporal and frontal involvement in task performance in aged individuals. Finally, others support the view that aging does not simply reduce activation in one region as the FAH would predict, but alters the *dynamics* within processing networks (Grady et al, 1994; Schacther et al., 1996 as cited in Greenwood, 2000). This approach advocates a departure from the traditional "localization" view to one in which brain dynamics and connectivity are emphasized.

Speed of information processing Salthouse:

The fundamental assumption in the processing speed theory of cognitive aging is that a major factor contributing to age-related differences in memory and other aspects of cognitive functioning is a reduction, with increased age, in the speed with which many cognitive operations can be executed (Salthouse, 1985, 1992, 1996; Rabbitt, 1997). In addition, studies have shown that age-related differences in fluid ability are attenuated by controlling for simple processing speed (Hertzog, 1989; Schaie, 1989; Schretlen et al., 2000). For example, using hierarchical multiple regression, Salthouse (1991) found that age alone accounted for up to 31% of the variablity in measures of reasoning among healthy adults between the ages of 20 to 84 years. After removing the variance associated with simple perceptual comparison speed and working memory, age effects on reasoning were reduced to less than 5% of the explained variance. Others have found that perceptual comparison speed alone markedly reduced the variance in fluid intelligence explained by age in a sample of healthy adults between the ages of 20 and 92 years (Hertzog, 1989; Schretlen et al., 2000).

The findings of Robbins et al (1998) did not support a strong version of Salthouse's (1985,1996) speed of information processing theory. Specifically, in a sample of normal volunteers ranging in age from 21 to 79 years who were administered the CANTAB, a neuropsychological test battery considered to be sensitive to frontal lobe functioning (Robbins et al., 1996), age and speed of processing were associated with most of the CANTAB measures. Age-related variance was significantly reduced in most of the measures when controlling for speed. However, speed did not account for the variability in performance on all of the tests in this battery. For example, controlling for age rendered the correlations between speed and both spatial working memory and attentional set-shifting non-significant, suggesting that variance associated with information-processing rate was not primarily associated with these tests, and that age alone accounted for some of the variability in performance. These results were compatible with those reported by Rabbitt and Maylor (1991) and Baddeley (1996), which suggest that certain EF may be related to age, over and above any relationship with speed of processing and/or IQ.

Fluid intelligence versus "EF":

According to Spearman (1927), performance on a wide range of different intelligence tests can be described by a single, higher order statistical construct defined as 'g' (as cited in Rabbitt, 1997). Duncan et al (1995) have shown that in groups of patients with focal frontal lobe damage, correlations between levels of performance on different tests of EF are modest and disappear when variance associated with individual differences in intelligence test scores is taken into consideration. These researchers suggest that tests of frontal functions are not only similar to tests of fluid intelligence in that they are measures of global and diffuse rather than specific skills that the classic tests assume them to be, but that measures of general fluid intelligence are actually the best empirical measure of frontal/executive functioning. This notion is contrary to the conventional belief in neuropsychology that EF are not related to psychometric intelligence (Duncan et al., 1995). For example, patients with noted EF deficits are said to have impaired planning or problem solving ability but intact intelligence. Yet, studies that have examined patients with frontal lobe impairment have generally used standard tests of intelligence such as the WAIS. The knowledge-based or, crystalized, intelligence subtests of the WAIS typically have a low correlation with g (as cited in Rabbitt, 1997). Crystallized intelligence may reflect g at the time of learning rather than at the time of test (Duncan et al., 1995). Tests of fluid intelligence, on the other hand, have strong correlations with g, thus are more closely related to g than are subtests of crystallized intelligence. These tests involve novel problem solving with spatial tasks or other tasks (Duncan et al., 1995).

To test the hypothesis that frontal/executive functioning is dependent upon fluid intelligence, Duncan et al (1995) examined frontal lobe damaged patients with intact superior IQ on both the WAIS and on Cattell's Culture Fair Test, a well-known test of fluid intelligence. They found that although WAIS IQ was preserved in the patients to the extent that even performance on tests within the non-verbal domain was intact, re-testing with the Culture Fair test revealed substantial deficits. They found no discrepancy between WAIS and Culture Fair IQ in posterior patients. Given these findings, Duncan et al suggest that g is a reflection of frontal function because individuals with preserved IQ, as assessed by the WAIS, and frontal impairment are substantially impaired in the Cattell Culture Fair fluid intelligence index, which is highly correlated with g. These findings, however, may only be applicable to those with superior premorbid IQ because in a follow-up study (Duncan et al., 1995b), these researchers failed to find as substantial a deficit in fluid intelligence in individuals who were of average IQ as was found in their prior study with individuals of superior premorbid IQ. However, it should be noted that the decrement in performance on tests of fluid intelligence by individuals in the latter study was highly significant.

Using factor analysis, Rabbitt (1997) found that among healthy older adults, executive tasks did not load on a common factor and the association between EF task performances was entirely accounted for by a common loading with intelligence. However, Lowe and Rabbitt (1997) found that age-related variance on executive tasks remained after controlling for speed and intelligence, thus giving support to the notion that age accounts for some of the variance in performance in EF tasks over and above speed of processing and intelligence. Thus, controversy exists regarding EF and fluid intelligence. To date, studies have not examined the degree to which a 'global' versus a 'multidimensional' EF construct best discriminates among different groups of individuals (e.g., younger versus older; impaired versus normal).

MILD COGNITIVE IMPAIRMENT, ALZHEIMERS DISEASE, AND EF

Frontal, or executive, deficits are part of the diagnostic constellation of many types of disorders (e.g., Attention-deficit Hyperactivity disorder, Antisocial Personality disorder, Schizophrenia, Frontotemporal dementia, Parkinson's disease). Until recently, executive dysfunction was generally considered to be a late occurrence in Alzheimer's disease (AD), although recent studies indicate that EF deficits are apparent in the early stages of the disease (Binetti et al., 1996; Chen et al., 1998; Collette et al., 1999), and can differentiate among those with MCI, thought to be a prodromal stage of AD, who will decline versus those with MCI who will not (Lafleche & Albert, 1995; Albert, 1996; Albert et al., 2001). In fact, several lines of research now suggest that EF deficits may be the best predictors of progression to AD among individuals diagnosed with MCI. This finding is important in light of the fact that previous studies have focused primarily on memory deficits, specifically, a decline in episodic memory, as a tell-tale sign of advancing dementia or AD. However, a decline in episodic memory is evidenced in MCI (in which half of individuals will progress to AD and the other half will not) and normal aging as well. Others have found that definitions of MCI focusing primarily on memory impairment, to the exclusion of other cognitive domains, are poor predictors of dementia within a three-year follow up period (Ritchie et al., 2001 as cited in Kluger et al., 2002). Thus, although memory indices have been central in distinguishing who among the elderly will progress to dementia (Jacobs et al, 1995; Masur et al., 1989; 1994), memory decline alone may not be adequate, and an impairment in other cognitive domains such as EF, may increase diagnostic accuracy, as well as increase the accuracy of prognostic prediction very early on regarding who among the elderly are likely to develop AD.

Mild cognitive impairment is conceptualized differently among various researchers. Specifically, MCI has been conceptualized as a transitional state between aging and dementia, a static impairment in which individuals with memory complaints and objective impairment are *unlikely* to progress to AD (Petersen et al., 1999), or early-stage AD (Bozoki et al., 2001; Hullette et al., 1998; Morris et al., 2001).

Research thus far has focused on distinguishing who among those with MCI will progress to more frank memory impairment, or more specifically, who will progress to AD. The hope in much of this research is to better characterize MCI so that intervention may be implemented early on, possibly with cholinesterase inhibitors which have been known to be effective in AD, to prevent or delay the onset of more frank memory loss and impairment. However, this endeavor has been complicated by the fact that no clear diagnostic criteria exist for MCI (Ritchie & Touchon, 2000). Furthermore, among the studies that have focused on individuals with memory loss, most have used neither similar MCI criteria nor tests for that matter, making comparison of findings difficult. Thus, questions remain regarding whether MCI is part of the normal aging process, a static memory impairment, or a prodromal stage of AD.

Individuals with MCI reportedly progress to AD at rates of 12% per year (Celsis, 2000). This would suggest that many individuals with MCI may possibly be in the very early stages of AD. Some researchers suggest that most MCI cases represent unrecognized AD (Morris et al., 2001), whereas others do not (Petersen et al., 1999) given the findings that not all patients with a 'diagnosis' of MCI will progress to AD. Interestingly, among the studies suggesting that most cases of MCI represent early-AD (Bozoki et al., 2001; Hullette et al., 1998; Morris et al., 2001), findings indicate that cognitive impairment in the sample of individuals recruited is generally not limited to memory loss, but involves other cognitive domains as well (see Kluger et al., 2002). In addition, although the Petersen criteria for MCI (Petersen et al., 1999) state that activities of daily living are not impaired, it may be that they very well are, however subtle (M. Sano, Ph.D., personal communication). A diagnosis of dementia involves memory loss accompanied by functional decline. Finally, in some studies investigating the MCI/early-AD hypothesis (e.g., Morris et al., 2001), post-mortem examination of brains of individuals who had been given diagnoses of MCI reveal that neuropathologic features are predominantly of AD.

According to Petersen et al (1996; 1999), although up to 55% of individuals diagnosed with this group's MCI criteria who were followed over a period of 4.5 years developed AD, nearly 45% of the sample diagnosed with MCI had *not* progressed to dementia. Thus, determining which clinical and/or neuropsychological features among individuals diagnosed with current conceptions of MCI is of vital importance. This is especially true of those who will progress to more frank memory impairment so that early intervention and treatment can be implemented. Early intervention may allow for relatively longer periods of adequate functioning. It is equally important for those who will not progress to allay any of the common fears that a failing memory entails for elderly individuals experiencing such problems.

AIMS AND HYPOTHESES OF THE PRESENT STUDY RESTATED.

The aims of the present study were three-fold. The first aim was to use a factor analytic approach to examine the construct of EF in a large sample of non-impaired individuals to determine: 1) the degree to which EF, independent of IQ, is a unitary versus a multi-dimensional construct, and 2) the degree to which neuropsychological tests of EF measure this single, 'global' construct and any identifiable sub-components. It was hypothesized that a single, global EF construct would be identified, within which exist separable sub-components.

The second aim was to examine the degree to which: 1) EF, as a 'global', unitary construct, independent of IQ, differs among younger (<54.11 years of age; mean age = 26) and older (≥55 years of age; mean age = 69) individuals, and 2) an age-related decline was evidenced on individual measures of EF. It was hypothesized that when both a global measure of EF, as well as individual test scores are examined, older individuals would perform more poorly than younger individuals, and that this difference would not be fully accounted for by measures of IQ.

The third aim was to further characterize the neuropsychological profile of MCI by examining whether those with MCI perform more poorly, relative to normal, age-matched controls, on tests of EF. Given the well-established finding of EF deficits in AD, along with the high rate of conversion of MCI to AD, it was hypothesized that individuals meeting the present study's criteria for MCI (see Table 1) would perform significantly worse than age-matched controls on EF tasks assessing working memory, response/behavioral inhibition, and semantic fluency.

Methods

Participants. Three groups of participants were enrolled in the study at two sites. Group 1 was comprised of young adults (YA) from Queens College. The QC recruitment consisted of students enrolled in introductory psychology classes, who volunteered three hours of their time to satisfy a course research requirement. All QC participants were under the age of 54 years (mean age = 25.2[9.6]), with most individuals in their twenties. The remaining two groups were older adult samples that were recruited at Columbia Presbyterian Medical Center (CPMC). Group 2 was comprised of normal older adults (mean age = 67.9[7.9]) and Group 3 of those deemed to have MCI (mean age = 72.0[8.6]). The two older groups did not differ in age (see Table 2). The OA and MCI participants were recruited via flyers and advertisements approved by the CPMC institutional review board (IRB), or through referrals by a spouse or friend. All participants from the three groups signed consent forms approved by each responsible IRB.

Table 2

Participants

	YA N = 100	OA N = 52	MCI N = 40	p-value
AGE** **YA<OA=MCI**	25.21(9.58)	67.88(7.87)	72.03(8.55)	.001
EDUCATION** **OA>YA=MCI**	13.65(.85)	15.96(2.72)	14.33(2.89)	.001
% FEMALE	72	81	68	NS
% RIGHT-HANDED	92	98	95	NS

Note: ** denotes p < .001

General inclusion exclusion criteria. All participants were native English speakers (or English was their primary language by no later than the age of 10 years). Exclusionary criteria were a history of neurological disease (e.g., epilepsy, Parkinson's disease, Alzheimer's disease [AD], stroke), a history of head injury with loss of consciousness within the past 2 years, psychosis or agitation, depression within the last one year, use of a psychoactive substance within the past week, or a medication regimen that included cholinesterase inhibitors (e.g., Aricept). Although depression was not formally assessed, all participants were briefly interviewed regarding the presence or absence of a mood disturbance. For example, all were asked the question: "Have you been depressed within the past year?". If a participant responded affirmatively, the following question was asked: "Have you been diagnosed with depression by a psychiatrist, therapist, psychologist, or any other mental health professional within the past year?". Data from participants that screened positive for depression were not included in the analyses. No formal toxicology screening method was used to determine psychoactive and recreational drug use. However, each participant was simply required to respond either yes or no to questions regarding ingestion of a controlled substance within the past week.

MCI Group. Participants were identified as MCI if: 1) they endorsed a memory complaint, 2) they considered their memory to be worse than peers, 3) their score on delayed recall of the Buschke Selective Reminding Test (SRT) was greater than, or equal to, one standard deviation below the mean of normative data (T-score of 40 or less; age-based norms courtesy of DM Jacobs, Ph.D.), 4) they were not diagnosed with any other neurological disorder (e.g., stroke, Parkinson's disease, Huntington's disease, AD, traumatic brain injury) and 5) they were not depressed (see Table 1). Memory complaint was assessed by a brief interview in which participants were asked the following questions: "Do you have a memory problem?"; "Is your memory worse than what it was?"; and "Do you think your memory is worse than others of the same age?". An affirmative response on these questions, along with poor performance on the SRT as described above, and the absence of depression (see above for a description of the brief screening procedure used to determine the presence of a mood disturbance) and neurological disorder, resulted in a participant's inclusion in the MCI group.

OA Group. The normal age-matched control group consisted of individuals who did not have a memory complaint, and whose score on delayed recall of the SRT was better than one standard deviation below the mean (T=41 or greater). When being interviewed for memory complaint, if some participants responded affirmatively, but responded negatively to follow-up questioning regarding memory complaint (e.g., "Do you think your memory is worse than others of the same age?"), they were included in the OA group. Data was not included from participants who during actual screening endorsed a memory problem that was worse than what it had been previously and was worse than others of the same age, but performed well within the normal range (in some cases, above average) on memory testing, or, conversely, if a memory problem was not endorsed, but the participant performed below the cut-off score on the SRT delayed recall. Demographics of the YA, OA, and MCI groups are presented in Table 3.

Table 3

GROUP DEMOGRAPHIC CHARACTERISTICS

	YA		OA		MCI		
	Mean	SD	Mean	SD	Mean	SD	value
Age[1]	25.2	9.6	67.9	7.9	72.0	8.6	.001
WAIS-III Vocabulary (standard score)[2]	11.5	3.1	14.1	3.0	11.9	3.4	.001
WAIS-III Block Design (standard score)	10.0	2.8	11.0	2.7	10.0	2.9	NS
WAIS-III Full Scale IQ (estimated)[2]	104.3	13.7	114.8	13.7	105.3	15.1	.001
Education[2]	13.7	0.8	15.9	2.7	14.3	2.9	.001
SRT (delay T score)	N/A	N/A	54.8	7.3	30.8	5.8	.001
WMS-III Visual Reproductions II (delay raw score)	N/A	N/A	58.8	24.0	32.6	21.4	.001

[1] "Young" < "Old" = "MCI"
[2] "Old" > "Young" = "MCI"

Screening Procedures (OA and MCI Groups). A total of 129 participants were screened at the Columbia site, among which 37 were excluded for not meeting study entry criteria. Specifically, 20 individuals were excluded for endorsement of a memory problem while scoring within normal limits on the SRT. Other exclusions were for the following reasons: 2 individuals were underage (in their early 50's), one participant had no memory complaint but had low memory scores, one participant had vision problems and could not see most of the test items, 3 were possibly demented and were referred to private physicians, one participant was on Aricept, and 9 responded affirmatively to questioning regarding depression. Several participants (N = 5) were recruited from an ongoing clinical trial examining the efficacy of estrogen replacement therapy to prevent or delay the onset of AD in women at risk (i.e., those who had a first degree relative with AD).

Since the SRT is administered to all participants in the estrogen trial, it was not re-administered to these 5 women during their participation in this study. Testing with the SRT, in all cases, had been completed within 3 months of the participants' enrollment in the present study, which raises the possibility of confounds. Two potential confounds associated with the inclusion of data from these participants are less time testing (approximately 10 minutes) and any cognitive effects associated with estrogen or placebo. Among these 5 women, four were included in the OA group and one in the MCI group.

Among the 92 participants comprising both the OA and MCI groups, 42 were not administered the modified Mini Mental State Examination (mMMSE; Stern et al., 1987), as this test was included after recruitment had been initiated and well underway. There were no significant differences among the individuals who were and were not administered the mMMSE in terms of education (t = 1.79, p = .08) or vocabulary scaled score (t=.283, p = .778). However, there was a significant difference among the participants who were and were not administered the mMMSE on SRT delayed T-score (t=2.42, p = .01) such that those who were administered the mMMSE had lower scores on the SRT delayed T-score (mean[SD] = 41.28[14.07]) as compared to those who were not administered the mMMSE (SRT delayed T-score mean[SD] = 48.12[12.51]). Block design scaled score approached significance (t=1.95, p = .054). Potential reasons for lower scores on SRT delayed T-score may be due to the more stringent recruitment procedures employed by the time that the mMMSE was included in the protocol (i.e., the recruitment of individuals with memory complaints, which they believed were worse than their peers). As recruitment progressed, it became apparent that many more normal control participants had been recruited. Thus, the latter half of enrollment focused primarily on the recruitment of MCI subjects, as early enrollment participants consisted primarily of individuals without memory problems, who met criteria for the OA group. Among the 52 participants enrolled in the OA group, 23 were administered the mMMSE as compared to 27 of the 40 participants enrolled in the MCI group.

Cognitive and Diagnostic Assessment.

1) Wechsler Adult Intelligence Scale, 3rd Edition (WAIS-III) Vocabulary and Block Design subtests. The Vocabulary and Block Design subtests from the WAIS-III were used as measures of estimated general intelligence for all participants (YA; MCI; OA). Both Vocabulary and Block Design subtests have been shown to be highly correlated with overall general intellectual functioning, and are reported to be accurate indicators of verbal and non-verbal abilities (Lezak, 1994; Silverstein, 1982; Sattler, 1988). Age-scaled scores from the Vocabulary and Block Design subtests were totaled and used to derive an estimated Full Scale IQ (FSIQ) for each participant based on an algorithm provided by Sattler and Ryan (1998). Vocabulary scaled score was used to control for estimated IQ. The rationale for using Vocabulary, rather than estimated FSIQ, was based on the notion that Vocabulary, rather than visual-spatial ability, as assessed by Block Design and the combination of the two subtests to derive the FSIQ estimate, is a more accurate measure of 'g', or crystallized intelligence, and less likely to be affected by executive functioning (Duncan et al., 1995). Hereafter, analyses conducted using

standardized, EF measures that are Vocabulary controlled will be referred to as "IQ-controlled".

2) Buschke Selective Reminding Test (SRT). The SRT was administered to all older individuals at the CPMC site in order to define the MCI and OA groups. The SRT assesses the acquisition, retention, and retrieval of a list of words. The total or delayed recall score on the SRT has been used in numerous studies examining the rate of progression to dementia of both healthy individuals and those with memory deficits or MCI (Jacobs et al., 1995; Masur et al., 1989; 1994). Participants were given six trials to learn a list of 12 unrelated words. After each recall attempt, a selective reminding procedure was used wherein subjects were reminded only of those words that had not been successfully recalled. To assess long-term retention of the word list, 15-minute delayed free recall was assessed, followed by a multiple-choice recognition task. Scores on delayed recall were used to identify the MCI group from that of the OA group. Specifically, T-scores that are greater than, or equal to, one standard deviation below the mean of normative data (T-score of 40 or less) resulted in a participant's inclusion in the MCI group and participants scoring above this cut-off (T-score of 41 or greater) were included in the normal control group (actual group inclusion depended upon participants meeting additional criteria; see above for detailed explanation).
3) Modified Mini-Mental Status Examination (MMSE). Slightly more than half of the participants recruited at the Columbia site (50/92) were administered the modified MMSE (Stern et al., 1987), which also derives a Folstein score (Folstein et al., 1975). The Folstein is used extensively in the neurological and

neuropsychological literature as a screening tool for dementia. See *Screening Procedures (OA and MCI Groups)* section above for details regarding reasons for screening only half the participants with this test.

Selection of EF Measures. The executive function battery used in the present study was selected after a careful literature review. Tests were selected on the basis of their history and use as "frontal/executive" tasks. Consecutive volumes of several neuropsychological journals (e.g., Journal of Clinical and Experimental Neuropsychology, Journal of the International Neuropsychological Society, Neuropsychology) were examined and the frequency of a particular tasks appearance in studies was recorded. Tasks that were over-represented in studies examining frontal/executive functions, and in which sufficient reliability and validity have been reported, were chosen for the present study. In addition to these "classic" tests of executive function, two computerized experimental laboratory tasks were used. Normative data for these two computerized tasks have been previously established (Mitsis and Halperin, 2002; Submitted).

Executive Function Measures.

1) Wisconsin Card Sorting Test (WCST). The WCST assesses the ability to identify an underlying principle without the benefit of overt instruction, and involves shifting of mental set. It is considered to be the premier test of EF, and has been used extensively in a multitude of studies investigating EF. To perform the test correctly, participants must first discover the rules of the test, realize that the rules are arbitrarily changed, and adjust their behavior to conform to the new rules. Four stimulus cards are placed in front of the participant. The cards display a red triangle, two green stars, three yellow crosses, and

four blue circles. There are two sets of cards consisting of 64 each for a total of 128 cards. The cards are to be sorted either by color, form, or number. Once the rule is identified (i.e., the participant begins to sort by color), the rule is suddenly changed (after 10 correct sorts) and the participant must figure out what the new 'rule' is (i.e., to sort by form). The examiner provides the participant with feedback for every sort by indicating whether the participant's sort of each card was 'correct' or 'wrong'. The test continues for a maximum of 10 correct sorts or until all the cards are used. The measures of performance most often used are the number of correct categories completed and the number of perseverative errors (Milner, 1963 as cited in Bryan and Luszcz, 2000). Perseverative errors occur when the participant continues to sort according to the criterion of the previous sort. In other words, the participant does not alter their performance to the changing demand/rule. The number of perseverative errors may reflect the extent to which a participant can demonstrate conceptual flexibility (Lezak, 1995). The number of perseverative errors was used as the dependent measure in the present study.

2) Tower of London (TOL). The TOL is used to assess planning (Lezak, 1995) or, more recently, inhibitory (Welsh et al., 1999) abilities, and was found to be sensitive to frontal lobe damage (Shallice and Burgess, 1991 in Bryan and Luzcsz, 2000). In this test, two boards upon which are 3 pegs of descending sizes are placed one in front of the other. One board is for the examiner's use and the other is for the participant. The examiner places a predetermined pattern of beads on his or her board. The participant must move the beads on their board (which is always in the same pattern at the start) to match the pattern on the examiner's board in as few moves as possible. One minute is allowed for

each problem. Total time to initiate the first move, execution time, and overall total time is calculated. The number of moves is counted and the number of time (>1 minute) and rule (e.g., removing more than one bead at a time from a peg) violations is scored. Total number of moves was used as the dependent measure.

3) Controlled Oral Word Association Test (FAS). Verbal fluency, as measured by FAS, measures the speed and ease of verbal production. Tests of verbal fluency require an individual to generate as many words as possible using an initial letter, thus providing an index of how well an individual organizes their thinking. The FAS consists of three word-naming trials. Participants must generate as many words as possible beginning with a designated letter (F, A, or S) as quickly as they can (total time for each letter is 1 minute). Total number of words generated across the three trials was used as the dependent measure.

4) Category fluency. Category fluency is a type of verbal fluency in which people are required to produce instances of a semantic category. For the duration of one minute per category, the participant is required to name as many different types of "animals", "food", and "clothing", as quickly as possible. This type of fluency may be more sensitive to age-related decline than is letter fluency (e.g., FAS), possibly due to an age-related decline in strategic search processes (Bryan and Luszcz, 2000). The dependent measure used was the total score on all three categories.

5) Stroop Color and Word Test. The Stroop requires the shifting of perceptual set in accordance with changing demands and the inhibition of an over-learned response in favor of a more effortful one. The current study utilized the Golden (1978) version of the Stroop, which involves three conditions lasting 45 seconds each. The first condition

required participants to read a list of color words printed in black ink as quickly as possible. The second condition required the participants to name the color of ink that groups of "X's" were printed in (e.g., XXXX appeared in the colors blue, green, and red). The third condition involved the presentation of color words printed in conflicting colored ink. The participant was instructed to name the color the word was printed in, without naming the word that was printed in each item. The interference score, which is calculated based on performance across the three conditions, was used as the dependent measure.

6) The Trail Making Test (TMT), Parts A and B. The TMT requires attention and concentration skills, and the ability to inhibit and regulate behavior. Trails A involves visual tracking, whereas Trails B, in addition to visual tracking, involves the ability to initiate, switch, and stop a sequence of behavior. In Part A, lines are drawn on a page to connect 25 consecutive, encircled numbers. The subject is instructed to draw the lines as fast as possible. Part B involves tracking, sustained attention, cognitive flexibility and shifting of perceptual set in that the subject must draw lines alternating between numbers and letters sequentially (for e.g., 1 to A, A to 2, 2 to B, and so on to the letter L and the number 13). Completion of Trails B typically requires a longer period of time than Trails A. The dependent measure used was the difference score (time in seconds to complete Trails B minus time in seconds to complete Trails A).

7) WAIS-III Letter-Number-Sequencing (LNS). Verbal working memory was assessed by the LNS subtest of the WAIS-III. The task requires examinees to order, sequentially, a series of numbers and letters orally presented by the examiner in a specified, random order. Thus, participants must simultaneously track letters and numbers, while

sequencing each of these stimuli without forgetting any part of the series. Raw score on LNS was used as the dependent measure.

8) WAIS-III Digit Span (DS). The DS subtest assesses basic auditory attention. A sequence of digits are orally presented by the examiner that must first be repeated forward and another sequence of digits are presented that must be repeated backward. The dependent measure used was DS backward score (DSB).

9) Competing Motors Program (CMP). Response inhibition and organization was measured using a computerized task modeled after Luria's Competing Motors Programs Test (Luria, 1973). Subjects were seated in front of a computer monitor with a standard keyboard on which labels indicating 1 and 2 were placed over the two central keys of the bottom row of letters (the B and N keys). The numbers 1 and 2 were presented individually in the center of the monitor for a total of 120 trials. The numbers were presented in random order across four 30-trial epochs that constitute two counterbalanced conditions (noncompeting and competing). In the two noncompeting conditions, subjects were instructed to press the key marked "1" when the "1" appeared on the screen and the key marked "2" when the "2" appeared. In the two competing conditions, subjects were instructed to press the key marked "2" when the "1" appeared on the screen and to press the key marked "1" when the "2" appeared. They were instructed to press the key as quickly as possible using only the index finger of their dominant hand. Numbers remain on the screen until the subject presses the key of choice, at which point, the next number appears. The numbers 1 and 2 appeared an equal number of times per condition. The difference score between competing and noncompeting conditions was used as the dependent measure.

10) Identical Pairs Continuous Performance Test (CPT). Sustained attention and working memory was assessed through the use of a CPT (Hinton et al, 1994). Four-digit numbers were presented on a computer monitor one at a time, in random sequence, until a total of 400 stimuli (4 epochs each with 100 stimuli) were presented. Subjects were told to press the space bar of the keyboard as quickly as possible whenever the same sequence of numbers appeared twice in a row. Each number sequence was presented for a duration of 200 ms, with an inter-stimulus interval of 1.5 sec. Total task duration was approximately 12 minutes. Prior to onset of the CPT procedure, a brief training trial was administered to ensure comprehension of the task. The CPT program generates scores for the number of hits, misses, false alarms, and mean hit reaction time (RT). Total errors (CPT misses plus CPT false alarms) were used as the dependent measure.

Data Analyses.

Statistical analyses were conducted using SPSS software (SPSS, Inc., 1999). The following hypotheses testing was undertaken:

Hypothesis 1: a unitary, 'global' EF construct, independent of IQ, will be identified, within which exists separable sub-components.

Data were initially visually inspected to determine whether scores for all EF measures were normally distributed. Logarithmic or square root transformation was applied on measures of EF to correct for non-normal distributions where necessary. Subsequently, parametric assumptions were met and all variables were normally distributed.

Vocabulary scaled score was used to control for estimated IQ. The rationale for using Vocabulary, rather than estimated FSIQ, was based on the notion that Vocabulary, rather than visual-spatial ability, as assessed by Block Design, is a more accurate measure of 'g,' and less likely to be affected by executive functioning (Duncan et al., 1995). Although the hypothesis states that IQ-controlled measures will be used, this remains a controversial issue in the field, thus data analyses will be conducted using both standardized, IQ-controlled EF measures and non-standardized, non IQ-controlled EF measures. Hereafter, analyses conducted using standardized EF measures that are Vocabulary controlled will be referred to as "IQ-controlled".

First, all EF test scores were converted to z-scores, while controlling for Vocabulary scaled score, and transformed, such that a higher score was associated with better performance. Specifically, each EF measure was used as the dependent variable and submitted to linear regression, with IQ entered as the independent variable. Standardized residuals for each EF measure were saved and renamed. Second, the ten IQ-controlled EF measures were submitted to Principal Components Analysis (PCA) with Varimax rotation.

The following standardized, IQ-controlled EF variables were used in the analyses: Digit Span backward (DSB), Letter-Number Sequencing (LNS), Competing Motors Program (CMP), Identical Pairs Continuous Performance Test (CPT), Stroop Interference (STROOP), Wisconsin Card Sorting Test Perseverative Errors (WCST-PE), Tower of

London (TOL), Trail Making Test (TMT), Category Fluency (CATFLU), and Verbal Fluency as obtained with FAS (VERFLU).

Hypothesis 1 will be supported if:

1. Tests of EF have a moderate to strong loading on the first un-rotated factor of a PCA. Loadings on the first component will account for a substantial proportion of the variance.
2. PCA with Varimax rotation results in separate factors that indicate loadings of tests of EF that are typically associated with a particular cognitive domain. That is, factors should be comprised of tests that are known to assess a common theoretical concept (e.g., working memory, behavioral inhibition).

Hypothesis 2: when a 'global' measure of EF, as well as the saved factor scores and individual test scores are examined, older, normal individuals will perform more poorly than younger individuals, and this difference will not be fully accounted for by measures of IQ.

To conceptualize EF as a unitary, 'global' measure, the mean, standardized, IQ-controlled EF test scores were added together and divided by the number of tests (10) to form a single, global EF measure. EF variables used in the analyses will be the same as those indicated for hypothesis 1.

To compare the YA and OA groups on the global EF measure, ANCOVA, using education and gender as covariates, was conducted. To compare the YA and OA groups on the saved factor scores as dependent measures and on individual test scores, MANCOVA, using education and gender as covariates, was conducted, followed by individual ANOVAs. The MCI group was not included in these analyses to avoid confounding the results with the inclusion of a group with possible brain damage.

Hypothesis 2 will be supported if:

1. There is a significant difference between the YA group and the OA groups on both the global measure of EF and the factor scores.
2. As predicted by the Frontal Aging Hypothesis (FAH), an age-related decline will be found on most tests of IQ-controlled EF, except for those measures typically found to be resistant to decline in aging (i.e., Verbal Fluency).

Hypothesis 3: Individuals with MCI will perform more poorly, relative to normal, age-matched controls, on tests of EF. In particular, individuals meeting the present study's criteria for MCI (see Table 1) will perform significantly worse than age-matched controls on EF tasks assessing working memory, behavioral inhibition, and semantic fluency.

To compare the OA and MCI groups on the global measure of EF, ANCOVA, using education and gender as covariates, was conducted. To compare the OA and MCI groups on the saved factor scores and individual test scores, MANCOVA, using education and gender as covariates, was conducted. EF variables used in the analysis will be the same as those indicated for hypotheses 1 and 2.

Hypothesis 3 will be supported if:

1. There is a significant difference between the OA and MCI groups on the global EF measure, the factor scores, and on individual measures of EF that purportedly assess EF (i.e., working memory, behavioral inhibition, and category fluency). There will be no difference in the 2 groups on tests of verbal fluency, as verbal abilities are generally resistant to decline in individuals in aging and in the early stages of AD.

RESULTS

The intercorrelation among IQ-controlled EF measures, are presented in Table 4. Consistent with findings in the literature, measures of EF were weakly to modestly correlated with each other, including those tests that purportedly measure similar constructs.

Hypothesis Testing.

Hypothesis One: Principal Components Analysis was conducted to examine the construct validity of EF. Specifically, the first hypothesis, that a single, global EF will be identified within which exist separable sub-components, was examined via PCA with Varimax rotation. Factor 1 of the PCA had an eigenvalue of 3.00 and accounted for 30%

of the variance (see Table 5 and Figure 1). As indicated in Table 5, EF tests, with the exception of Stroop Interference, had a moderate to strong loading on this first factor.

Table 5

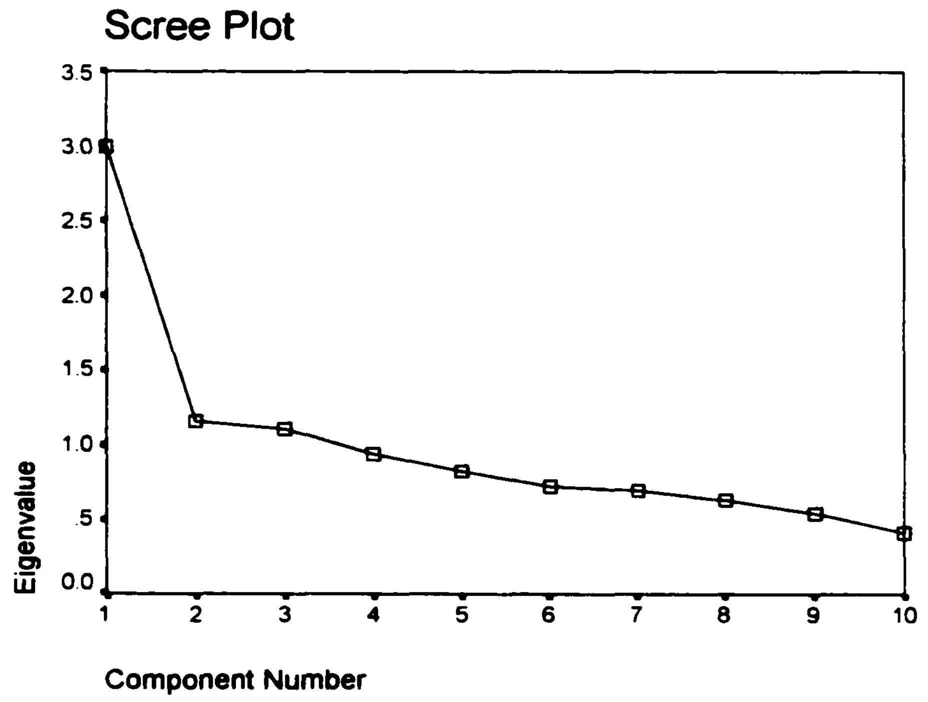
Un-Rotated Matrix of IQ-Controlled EF measures for the YA, OA, and MCI Groups

	Factor 1	**Factor 2**	**Factor 3**
LNS	-.728	--	--
TMT	.691	--	--
WCST-PE	.594	--	--
CATFLU	-.596	.530	.407
CMP	.523	--	--
CPT	.518	.494	.508
TOL	.492	--	.487
DSB	-.448	--	.573
VERFLU	-.452	.690	--
STROOP	--	--	-.648

Note: -- represents factor loadings < .40

Figure 1

Scree Plot of Un-Rotated IQ-Controlled EF measures for the YA, OA, and MCI Groups



Varimax rotation on standardized, IQ-controlled, EF measures generated a 3-factor solution accounting for 53% of the variance. These factors were tentatively labeled "working memory" (DSB, LNS, CPT, TMT, and CMP), "behavioral inhibition" (TOL and STROOP), and "fluency" (VERFLU and CATFLU) (see Table 6 below).

Table 6

Rotated Component Matrix of IQ-Controlled EF Measures for YA, OA, and MCI Groups

	Factor 1 **"working memory"**	**Factor 2** **"fluency"**	**Factor 3** **"behavioral inhibition"**
DSB	-.693	--	--
CPT	.674	--	--
LNS	-.719	--	--
WCST-PE	--	--	--
TMT	.583	--	--
CMP	.407	--	--
TOL	--	--	.639
STROOP	--	--	-.757
CATFLU	--	.763	--
VERFLU	--	.825	--

Note: -- represents factors with a loading < .40

PCA of IQ-controlled EF measures using the YA and OA groups only.

PCA, using IQ-controlled EF measures was also conducted eliminating the MCI group from the analysis to determine whether the principal components, before and after rotation, would be altered as a function of removing individuals with probable brain dysfunction. As indicated in Tables 7 and 8 and Figure 2 below, the eigenvalue for the first component, scree plot, and the factor structure of rotated components is highly similar to PCA in which the MCI group was included. The first principal component of un-rotated measures resulted in an eigenvalue of 2.81 and accounted for 28% of the variance. After Varimax rotation, 3 factors accounted for 51% of the variance. CMP loads less heavily when the MCI Group is eliminated from the analysis. Overall, factor analyses were not affected by the inclusion of this group.

Table 7

Un-Rotated Matrix of IQ-Controlled EF measures for the YA and OA Groups

	Factor 1	**Factor 2**	**Factor 3**
LNS	.706	--	--
TMT	-.616	--	--
WCST-PE	-.542	--	--
CATFLU	.590	.508	--
CMP	-.408	.406	--
CPT	-.502	.451	--
TOL	-.489	--	--
DSB	.515	--	.552
VERFLU	.511	.619	--
STROOP	--	-.417	-.506

Note: -- represents factors with a loading < .40

Figure 2

Scree Plot of Un-Rotated IQ-Controlled EF measures for the YA and OA groups

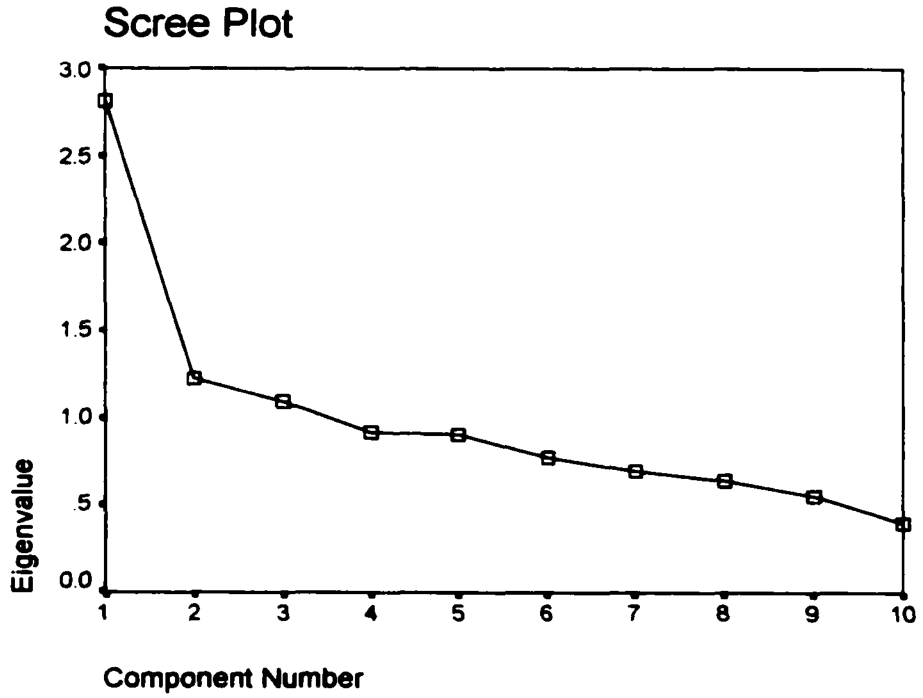


Table 8

Rotated Component Matrix of IQ-Controlled EF Measures for YA and OA Groups

	Factor 1 **"working memory"**	**Factor 2** **"fluency"**	**Factor 3** **"behavioral inhibition"**
LNS	-.733	--	--
DSB	-.718	--	--
CPT	.624	--	--
TMT	.545	--	--
STROOP	--	--	-.732
VERFLU	--	.819	--
CATFLU	--	.777	--
TOL	--	--	.575
WCST-PE	--	--	.441
CMP	--	--	.496

Note: -- represents factors with a loading < .40

PCA of *Non*-IQ-controlled EF measures using the YA, OA, and MCI groups.

Principal components analysis using non-standardized, non IQ-controlled EF measures for all three groups resulted in factor loadings, scree plot and an eigenvalue that were highly similar to those when using IQ-controlled measures (see Table 5 and Figure 1). Specifically, factor 1 accounted for 36% of the variance and resulted in an eigenvalue of 3.61. Most EF tests loaded moderately to substantially on the first factor with the exception of the Stroop (see Table 9 and Figure 3 below), as when using IQ-controlled measures.

Table 9

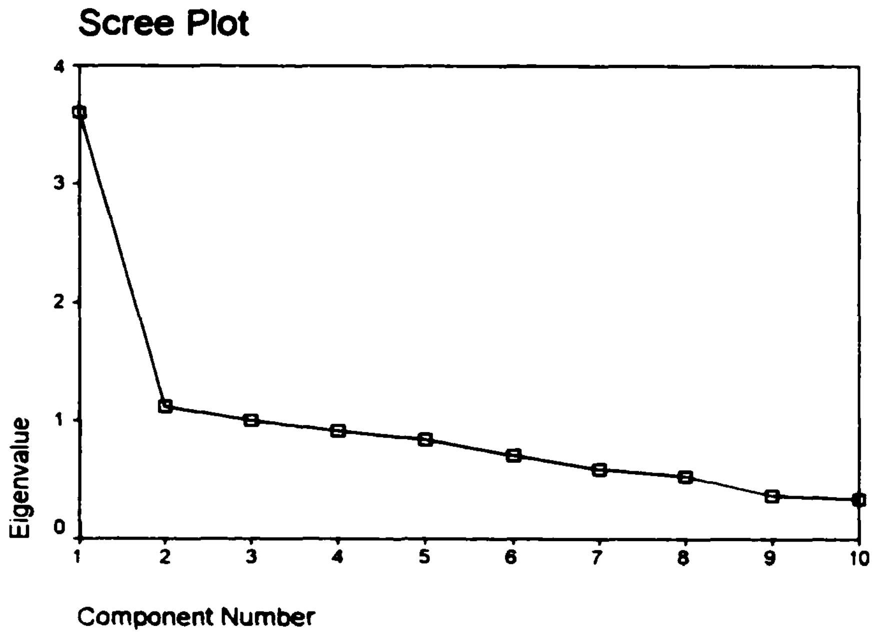
Un-Rotated Matrix of *Non*-IQ-Controlled EF measures for the YA, OA, and MCI Groups

	Factor 1	**Factor 2**
TMT	.768	--
LNS	-.746	--
CATFLU	-.693	--
WCST-PE	.651	--
VERFLU	-.603	.453
CMP	.599	--
TOL	.525	--
DSB	-.521	.465
CPT	.400	--
STROOP	--	-.448

Note: -- represents factors with a loading < .40

Figure 3

Scree Plot of Un-rotated *Non*-IQ Controlled EF Measures for YA, OA, and MCI Groups



Varimax rotation on non-standardized, non IQ-controlled, EF measures, including all three groups (YA, OA, and MCI) generated a 2-factor solution accounting for 47% of the variance. These factors were tentatively labeled "working memory/fluency" (DSB, LNS, VERFLU, CATFLU) and "behavioral inhibition" (WCST-PE, TOL, CPT, STROOP, CMP, TMT) (see Table 10).

Table 10

Rotated Matrix of *Non*-IQ-Controlled EF measures for the YA, OA, and MCI Groups

	Factor 1 **"working memory/fluency"**	**Factor 2** **"behavioral inhibition"**
VERFLU	.751	--
CATFLU	.703	--
DSB	.699	--
LNS	.692	--
TMT	-.460	.634
TOL	--	.637
CMP	--	.582
WCST-PE	--	.578
STROOP	--	-.571
CPT	--	.513

Note: -- represents factors with a loading < .40

<u>PCA of *Non*-IQ-controlled EF measures using the YA and OA groups only.</u>

PCA of non IQ-controlled EF measures was conducted eliminating the MCI group to avoid the possibility of including a group with possible brain damage. The initial un-rotated factor, scree plot, and eigenvalue were highly similar to those when standardized, IQ-controlled EF measures were used (see Table 7 and Figure 2). The first principal component of un-rotated measures resulted in an eigenvalue of 3.34 and accounted for 33% of the variance. Most EF measures loaded moderately to significantly on the first factor, with the exception of the Stroop (as when IQ-controlled measures are used) and the CPT. This latter variable has a moderate loading when IQ-controlled measures are used (see Table 7). Nevertheless, the factor loadings, using non-standardized, non IQ-controlled measures, are highly similar to the factor loadings when the MCI group is included (see Table 9 above).

Table 11

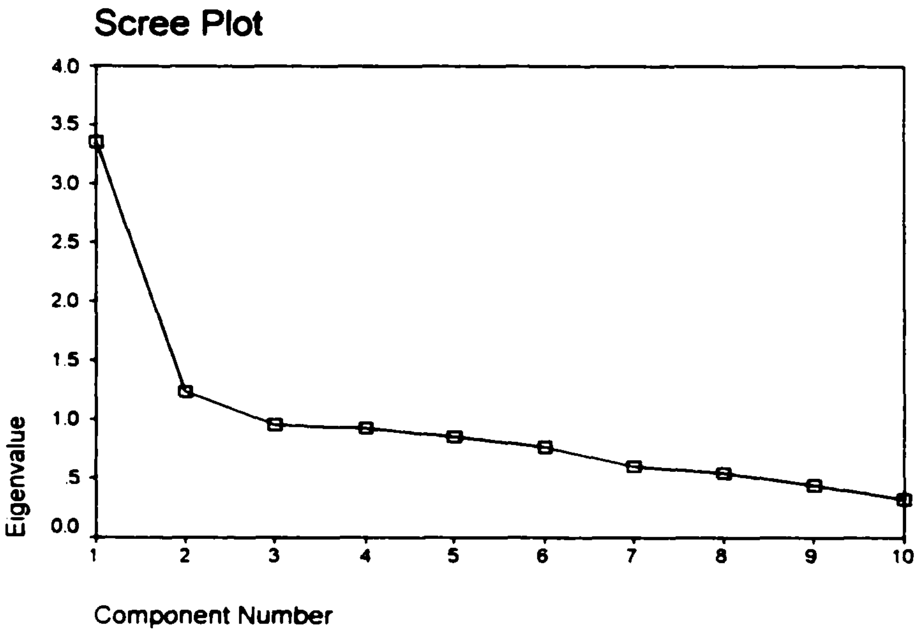
Un-Rotated Matrix of *Non*-IQ-Controlled EF measures for the YA and OA Groups

	Factor 1	**Factor 2**
LNS	.716	--
TMT	-.704	--
CATFLU	.674	--
VERFLU	.612	.483
WCST-PE	-.598	--
DSB	.585	.406
CMP	-.521	--
TOL	-.512	--
CPT	--	.464
STROOP	--	--

Note: -- represents factors with a loading < .40

Figure 4

Scree Plot of Un-rotated *Non*-IQ Controlled EF Measures for YA and OA Groups



Varimax rotation on non-standardized, non IQ-controlled, EF measures, including only the YA and OA groups, generated a 2-factor solution accounting for 46% of the variance. These factors were tentatively labeled "working memory/fluency" (DSB, LNS, VERFLU, CATFLU) and "behavioral inhibition" (WCST-PE, TOL, CPT, STROOP, CMP, TMT) (see Table 12 below). Thus, the factor structure was not affected by the inclusion of the MCI group (see Table 10 above) when using non IQ-controlled EF measures.

Table 12

Rotated Matrix of *Non*-IQ-Controlled EF measures for the YA and OA Groups

	Factor 1 **"working memory/fluency"**	**Factor 2** **"behavioral inhibition"**
VERFLU	.779	--
CATFLU	.734	--
DSB	.708	--
LNS	.684	--
WCST-PE	--	.606
TOL	--	.575
CPT	--	.591
STROOP	--	-.543
CMP	--	.580
TMT	-.424	.584

Note: -- represents factors with a loading < .40

Hypothesis Two: The second hypothesis of this study examined the degree to which EF, as a 'global', unitary construct, independent of IQ (as estimated using Vocabulary scaled score), differs among the YA and OA groups. Univariate ANCOVA, using education and gender as covariates was conducted. Alpha level was set at .05. As predicted, there was a highly significant difference between the groups on this 'global', EF measure (F = 16.48, p < .001). To examine whether older, normal individuals perform more poorly than younger individuals on the saved factor scores that were tentatively identified as "working memory", "behavioral inhibition", and "fluency" (see Table 8), Multivariate Analysis of Covariance (MANCOVA), using education and gender as covariates, was conducted.

In the following analyses, MANCOVA, rather than a series of ANCOVA's, was used to protect against inflated Type I error due to multiple tests of correlated dependent measures (see Table 4—correlations). Alpha level was set at .05 and Bonferroni correction was applied to the subsequent ANOVAs to adjust for multiple comparisons. MANCOVA for the 3 factor scores generated a Wilks Lambda of .85, which was highly significant (p < .001) thus allowing for univariate analysis of factor scores.

As expected, there was a significant difference between the YA group as compared to the OA group on the working memory (F = 17.17; p < .001) and behavioral inhibition factors (F = 5.11; p = .03) such that the YA group performed better, but not on the fluency factor (F = .153, p = .696; see Table 13).

Table 13

Differences Among YA and OA Groups on Saved Rotated IQ-Controlled Factor Scores

	GROUP	**Mean**	**SE**	**F**	**p**
Factor 1 "working memory"	YA	-.43	.10	17.17	.001
	OA	.35	.14		
Factor 2 "fluency"	YA	.10	.11	.153	.696
	OA	.00	.16		
Factor 3 "behavioral inhibition"	YA	-.22	.11	5.11	.03
	OA	.23	.16		

Hypothesis 2 was further examined using the 10 IQ-controlled, individual EF measures. MANCOVA, using education and gender as covariates, was conducted. In the following analyses, MANCOVA, rather than a series of ANCOVA's, was used to protect against inflated Type I error due to multiple tests of correlated dependent measures (see Table 4—correlations). Alpha level was set at .05 and Bonferroni correction was applied to the subsequent ANOVAs to adjust for multiple comparisons. MANCOVA for the 10 individual IQ-controlled EF scores generated a Wilks Lambda of .73 ($p < .001$), allowing for univariate analysis of individual scores.

When each EF measure was used in a MANCOVA, with education and gender as covariates, results indicated significant age effects between the YA and OA groups on LNS, CPT, WCST-PE, TMT, and CMP (see Table 14 below). Two of the measures in which significant differences were found were those presumed to measure behavioral inhibition (e.g., CMP, and WCST-PE). The other three measures were those purported to measure working memory (e.g., LNS, TMT, and CPT). No age effects were found on DSB, VERFLU, CATFLU, STROOP, and TOL. Thus, these results partially support hypothesis 2 in that age effects were noted on 5 of the 10 measures.

Table 14

Difference Between YA and OA Groups on Individual IQ-controlled EF Measures

Dependent Variable	**F**	**P**
LNS	6.310	.013
CMP	9.590	.002
CPT	13.092	.000
TMT	20.891	.000
WCST-PE	23.488	.000
TOL	1.450	.230
CATFLU	1.276	.260
DSB	.117	.733
STROOP	.112	.738
VERFLU	.001	.979

The degree to which EF, as a 'global', unitary construct, differs among the YA and OA groups when using non-standardized, non IQ-controlled measures was examined.

Univariate ANCOVA, using education and gender as covariates was conducted. Alpha level was set at .05. As predicted, there was a highly significant difference between the groups on this 'global', EF measure non IQ-controlled measure ($F = 10.79$, $p = .001$). To examine whether older, normal individuals perform more poorly than younger individuals on the saved factor scores that were not controlled for IQ and that were tentatively identified as "working memory/fluency" and "behavioral inhibition", (see Table 12 above), Multivariate Analysis of Covariance (MANCOVA), using education and gender as covariates, was conducted.

In the following analyses, MANCOVA, rather than a series of ANCOVA's, was used to protect against inflated Type I error due to multiple tests of correlated dependent measures (see Table 4—correlations). Alpha level was set at .05 and Bonferroni correction was applied to the subsequent ANOVAs to adjust for multiple comparisons. MANCOVA for the 2 factor scores generated a Wilks Lambda of .87, which was highly significant ($p < .001$) thus allowing for univariate analysis of factor scores.

As expected, there was a significant difference between the YA group as compared to the OA group on the behavioral inhibition factor ($F = 22.93$; $p < .001$) such that the YA group performed better; however, there was no difference among the 2 groups on the working memory/fluency factor ($F = .014$; $p = .905$; see Table 15).

Table 15

Differences Among YA and OA Groups on Saved Rotated *non* IQ-Controlled Factor Scores

	GROUP	Mean	SE	F	p
Factor 1 "working memory/fluency"	YA	.00	.102	.014	.905
	OA	.00	.149		
Factor 2 "behavioral inhibition"	YA	-.31	.100	22.93	.001
	OA	.602	.147		

Hypothesis 2 was further examined using the 10 non-standardized, non IQ-controlled, individual EF measures. MANCOVA, using education and gender as covariates, was conducted. In the following analyses, MANCOVA, rather than a series of ANCOVA's, was used to protect against inflated Type I error due to multiple tests of correlated dependent measures (see Table 4—correlations). Alpha level was set at .05 and Bonferroni correction was applied to the subsequent ANOVAs to adjust for multiple comparisons. MANCOVA for the 10 individual *non* IQ-controlled EF scores generated a Wilks Lambda of .79 (p = .001), allowing for univariate analysis of individual scores.

When each non IQ-controlled EF measure was used in a MANCOVA, with education and gender as covariates, results indicated significant age effects between the YA and OA groups on four of the 10 measures (CPT, WCST-PE, TMT, and CMP; see Table 16 below). Three of the measures in which significant differences were found were those presumed to measure behavioral inhibition (e.g., CMP, TMT, and WCST-PE). The other measure was one that purportedly measures working memory (CPT), although this measure appears to represent a "behavioral inhibition" variable when non IQ-controlled measures are used rather than when using IQ-controlled measures (see Tables 8 and 12 of factor loadings after varimax rotation). No age effects were found on DSB, VERFLU, CATFLU, STROOP, and TOL. Surprisingly, when non-IQ controlled measures are used, there are no group differences among the YA and OA groups on LNS. Thus, when using non-standardized, non IQ-controlled EF measures, hypothesis 2 is partially supported in that age effects were noted on 4 of the 10 measures (see Table 16).

Table 16

Difference Between YA and OA Groups on Individual *Non* IQ-controlled EF Measures

Dependent Variable	**F**	**P**
WCST-PE	18.16	.001
TMT	11.27	.001
CPT	4.78	.031
CMP	4.60	.034
TOL	1.83	.178
LNS	1.74	.189
VERFLU	.503	.479
DSB	.247	.620
CATFLU	.240	.625
STROOP	.042	.838

Hypothesis 3: *Individuals with MCI will perform more poorly, relative to normal, age-matched controls, on the global EF measure, the factor scores, and on individual measures of EF that purportedly assess working memory, behavioral inhibition, and category fluency. In particular, individuals with MCI will perform significantly worse*

than age-matched controls on EF tasks assessing working memory, inhibition, and semantic fluency.

To examine the degree to which EF, as a 'global', unitary construct, independent of IQ (as estimated using Vocabulary scaled score), differs among the OA and MCI groups univariate ANCOVA, using education and gender as covariates, was conducted. Alpha level was set at .05. There was no significant difference between the OA and the MCI groups on the global EF measure (F = 1.63; p = .21). When non-standardized, non IQ-controlled measures were calculated to create a 'global', unitary construct (i.e., raw scores were added together and divided by the number of tests) and used in the analysis, the 'global', unitary EF construct approached significance (F = 3.82; p = .055).

To examine whether older, normal individuals perform more poorly than individuals with MCI on the saved factor scores that were tentatively identified as "working memory", "behavioral inhibition", and "fluency" (see Table 6), MANCOVA, using education and gender as covariates, was conducted. MANCOVA, rather than a series of ANCOVA's, was used to protect against inflated Type I error due to multiple tests of correlated dependent measures (see Table 4—correlations). Alpha level was set at .05 and Bonferroni correction was applied to the subsequent ANOVAs to adjust for multiple comparisons. MANCOVA for the 3 factor scores generated a Wilks Lambda of .97, which was not significant (p = .458), thus not allowing for univariate analysis of factor scores.

To examine whether OA and MCI groups differed on the 2 saved factor scores in which non-standardized, non IQ-controlled measure were used and that were tentatively labeled "working memory/fluency" and "behavioral inhibition" (data not shown), MANCOVA, using education and gender as covariates, was conducted. MANCOVA, rather than a series of ANCOVA's, was used to protect against inflated Type I error due to multiple tests of correlated dependent measures (see Table 4—correlations). Alpha level was set at .05 and Bonferroni correction was applied to the subsequent ANOVAs to adjust for multiple comparisons. MANCOVA for the 2 factor scores generated a Wilks Lambda of .96, which was not significant (p = .178), thus not allowing for univariate analysis of factor scores.

MANCOVA, using education and gender as covariates, was conducted with the 10 IQ-controlled and non IQ-controlled EF dependent measures used in the above analyses. Alpha level was set at .05 and Bonferroni correction was applied. Once again, MANCOVA, rather than a series of ANCOVA's, was used to protect against inflated Type I error due to multiple tests of correlated dependent measures (see Table 4—correlations).

MANCOVA for the 10 IQ-controlled EF measures generated a Wilks Lambda of .88, which was not significant (p = .357), thus not allowing for multivariate analyses. MANCOVA for the 10 non-standardized, non IQ-controlled EF measures generated a Wilks Lambda of .87, which was not significant (p = .514), thus not allowing for multivariate analyses.

Post-hoc analyses.

Post-hoc exploratory analyses was conducted using separate ANCOVA's to examine whether the OA and MCI groups differed on the saved factor scores and on the 10 IQ-controlled EF measures. For both analyses, alpha level was set at .05 and Bonferroni correction was applied to the subsequent ANOVAs to adjust for multiple comparisons.

Despite using a less conservative statistic, no significant differences were found between the two groups on any of the 3 IQ-controlled factor scores. Separate ANCOVA's for each IQ-controlled EF measure resulted in a significant difference in CMP performance (F = 4.60; p = .04) between the OA and MCI groups. LNS approached significance (F = 3.84; p = .053), as did CATFLU (F = 3.31; p = .07). Thus, when using a less conservative statistic, while controlling for education and gender, the only significant difference that emerges among the OA and MCI groups is on a task that purportedly measures behavioral inhibition (CMP).

Post-hoc exploratory analyses was conducted on the 10 non-standardized, non IQ-controlled EF measures. For these analyses, alpha level was set at .05 and Bonferroni correction was applied to the subsequent ANOVAs to adjust for multiple comparisons. Separate ANCOVA's for each non-standardized, non IQ-controlled EF measure resulted in significant differences in CMP (F = 5.78; p = .02), LNS (F = 5.42; p = .02), and CATFLU (F = 5.67; p = .02) performances between the OA and MCI groups. Thus, when using a less conservative statistic, while controlling for education and gender and using non IQ-controlled EF measures, hypothesis 3 is supported in that these tests are those believed to measure behavioral inhibition (CMP), working memory (LNS), and semantic fluency (CATFLU).

Discussion

The aims of the present study were three-fold. The first aim was to use a principal components factor analytic approach to examine the construct validity of EF in a large sample of non-impaired individuals to determine: 1) the degree to which EF, independent of IQ, is a unitary versus a multi-dimensional construct, and 2) the degree to which neuropsychological tests of EF measure this single, 'global' construct and any identifiable sub-components. It was hypothesized that a single, global EF construct would be identified, within which exist separable sub-components. The second aim was to examine the degree to which: 1) EF, both as a 'global', unitary construct, and as more specific factors and test scores, differs among younger and older individuals. It was hypothesized that older individuals would perform more poorly than younger individuals on most measures, other than those believed to be resilient to aging (i.e., verbal fluency), and that this difference would not be fully accounted for by measures of IQ. Finally, the third aim was to further characterize the neuropsychological profile of MCI by examining whether those with MCI perform more poorly, relative to normal, age-matched controls, on measures of EF. Given the well-established finding of EF deficits in AD, along with the high rate of conversion of MCI to AD, it was hypothesized that individuals meeting the present study's criteria for MCI (see Table 1) would perform significantly worse than age-matched controls on EF tasks assessing working memory, behavioral inhibition, and semantic fluency.

Construct validity of EF: Hypothesis 1.

The present study's first hypothesis was supported by the data. Principal Components Analysis of IQ-controlled EF measures resulted in an initial un-rotated factor that accounted for 30% of the variance, thus indicating that an identifiable construct of EF exists, independent of IQ. All but one of the individual EF tests used in this study had at least a moderate loading on this first factor, suggesting that they tap into this unitary construct. In addition, PCA with Varimax rotation resulted in 3 separable components that accounted for 53% of the variance among the EF measures administered. Thus, these results are consistent with the findings of others (Baddeley and Della Salla, 1998; Duncan et al., 1996; Duncan et al., 1997; Engle et al., 1999; Kimberg and Farah, 1993; Mitsis and Halperin, 2001; Miyake et al., 2000), which suggest that EF is comprised of both unitary and multidimensional components. The rotated factor structure of all IQ-controlled EF measures was not altered substantially by the inclusion or exclusion of the MCI group. These findings were similar to those when non-standardized, non IQ-controlled EF measures were used, with the exception of the multidimensional aspects. Specifically, when non IQ-controlled EF measures are subjected to varimax rotation, only 2 factors emerged as opposed to 3 when using IQ-controlled. Interestingly, after applying rotation to non IQ-controlled measures, the emergent factors appeared to strongly represent a "cognitive" factor (i.e., DSB, LNS, VERFLU, CATFLU) versus a "behavioral inhibition" factor in that all tests loading on this second factor are those often described as requiring some level of inhibition or selfregulatory control (WCST-PE, TMT, CPT, CMP, STROOP, TOL).

Results of the current study differ from those of Rabbitt (1997) in that these findings indicate the construct of EF remains identifiable, in a large sample of individuals, while controlling for IQ. Previous studies did not control for IQ in their investigations of EF. Rabbitt (1997) found that most EF tasks did not load on a common factor and that the association between EF task performances was entirely accounted for by a common loading with intelligence.

The current findings lend support to the notion in conventional neuropsychology that EF are independent of psychometrically assessed intelligence per se, and may be impaired in the absence of a decline in IQ. This notion has been supported by early animal studies in which resection did not appear to have an impact on intelligence, but rather lead to a host of behavioral and 'personality' changes in the animals (Benton, 1991; Tranel et al., 1994). Finally, the current results are consistent with recent conceptions of EF, which suggest that there may be some unifying mechanism that may characterize the nature of EF deficits in frontal lobe patients (Duncan et al., 1996, 1997; Engle et al., 1999; Kimberg & Farah, 1993; Miyake & Shah, 1999).

Exploratory factor analytic approaches have been criticized as deriving factors that are defined arbitrarily and post-hoc, and as using terms (i.e., "inhibition", "set-shifting") that have not been independently tested. However, the present findings, in which IQ was controlled, resulted in most EF measures that are believed to measure a particular theoretical concept consistently loading on separate factors. For example, among the rotated factors, the working memory factor was comprised of LNS, DSB, TMT, and identical pairs CPT, measures that are believed to draw upon the ability to hold information 'on-line' while actively performing some cognitive manipulation of both orally- (LNS, DSB) and visually- (CPT, TMT) presented verbal material. Clinically, both LNS and DSB are used as measures of working memory and are two subtests of the WAIS-III, along with mental arithmetic, to comprise that scale's working memory index (Psychological Assessment Corp., 1994). The CPT that was used in this study is an experimental laboratory paradigm, which requires the ability to hold rapidly presented visual information 'on line', while remembering previously presented numbers for comparison. The TMT involves the active manipulation and sequencing of both numbers and letters.

The behavioral inhibition factor included the STROOP, WCST-PE, TOL, and CMP, all of which are believed to rely upon the ability to inhibit and regulate ongoing goal-directed behavior (Robbins, 1996; Shallice & Burgess, 1993). The Stroop and WCST-PE have been used extensively in the neuropsychological literature and have long been considered measures of behavioral inhibition. Although the TOL has been associated with planning, recent conceptions view it primarily as a test of inhibitory control (Robbins, 1996; Welsh et al., 1999). The CMP is based on Luria's competing motors programs, a classic measure of one's ability to exercise inhibitory control.

The third factor derived in this study included both fluency measures (VERFLU and CATFLU), which are believed to be dependent upon efficient organization and retrieval of information from linguistic and semantic stores involving the recruitment of frontal and temporal-parietal regions, respectively.

Age Effects: Hypothesis 2.

The second hypothesis examined the global, unitary EF construct, as well as the saved rotated factor and individual test scores, and the extent to which they differed between the younger group and the older, normal controls. Significant age effects were observed on the global EF measure, such that the young adults outperformed the older adults. Among the saved factor scores, as predicted, age effects were noted on the factors that were labeled "working memory" and "behavioral inhibition", but not on the "fluency" factor. This finding lends support to the notion that verbal fluency is relatively resistant to the normal aging process, while inhibition and working memory (West, 1996) are functional properties that gradually decline with age.

Hypothesis 2 was further partially confirmed when the 10 IQ-controlled EF measures were examined separately; significant age effects were observed on 5 of the 10 measures. Thus, results suggest that age has an impact on successful performance on over half the tests of EF used in this study, such that performance decreases as a function of increasing age. Among the individual tests, those that assess working memory (LNS, TMT, and CPT) and behavioral inhibition (CMP and WCST-PE) were significant, but those assessing fluency (VERFLU and CATFLU) and two tests of behavioral inhibition (STROOP and TOL) were not.

A potential explanation for the finding that a difference in performance was noted on three of the five tasks of behavioral inhibition may be related to the lack of clarity with regard to the underlying abilities that are tapped by executive tasks. This notion is reflected in the proliferation of terms and concepts used to characterize different EF tasks. For example, the interference section of the Stroop has been variously referred to as a test of "selective attention", "set shifting", and/or "inhibition", all of which are terms that have yet to be independently tested. Alternatively, the findings may be related to the low correlation among tests of EF that are believed to measure the same theoretical concept (see Table 4 for correlations among measures). For example, Rabbitt (1997) reported a failure to find a difference in inhibition between a variety of logically identical, but superficially dissimilar, Stroop-like tasks among healthy older adults. In addition, the TOL is considered a test of inhibition, but its correlation with other tasks of inhibition is weak or moderate at best (see Table 4).

It is a well-established finding in the neuropsychological literature, and in clinical settings, that individuals with frontal lobe sequelae often perform within the impaired range on some tests of EF, but perform well within normal limits on others that purportedly measure the same or a similar construct. For example, some patients may fail the Wisconsin Card Sorting test (WCST), but not the Tower of London (TOL), tests that are purported to tap in to similar functional abilities. Further complicating matters are other patients who may show the opposite pattern (e.g., fail the TOL but not the WCST).

One explanation for the differential pattern of performance by frontal lobe patients on EF tasks has given rise to the notion that EF may not be completely unitary (e.g., Godefroy, Cabaret, Petit-Chenal, Pruvo, & Rousseaux, 1999; Shallice, 1988). Conversely, findings have been related to the recruitment of different prefrontal brain areas (Stuss et al., 2003). Specifically, Stuss et al, using lesion data and a performance-based method of classifying frontal lobe patients into 4 groups (left and right dorsolateral, inferior and superior medial), found distinct roles for different frontal regions on separable cognitive processes using neuropsychological measures of EF (WCST, Stroop, FAS, and TMT). Using patient performances on the WCST as an example, these researchers found that damage to the inferior medial frontal area did not result in a deficit on the WCST; however, patients with superior medial damage, right or left, tended to be the most impaired on all measures (categories achieved, perseveration). Right and left lateral damaged patients were also significantly impaired, although less so than the superior medial group.

Thus, the present findings are similar to other studies in that results may reflect 1) lack of clarity with regard to the specific functional abilities that tasks of EF assess, 2) the notion of EF task impurity, 3) the unitary versus multidimensional aspects of EF, 4) differential recruitment of frontal brain areas, and/or 5) the reciprocal contributions from frontal and posterior regions in the successful completion of EF tasks.

The present results partially confirm the frontal aging hypothesis (West, 1996). Although no overall measure of speed of information processing (e.g., reaction time) was used in this study to examine whether age-related variance remains after controlling for speed, it is notable that two tests among the five that differed across age were associated with speed (CPT, TMT) and two were not (LNS, WCST-PE). Thus, it appears as though speed per se may not have contributed to the present results.

These findings also indicate the importance of using an age-appropriate comparison group, or normative data, when evaluating older individuals clinically or for research purposes. This study's findings raise concern about previous findings, whether from clinical or research settings, in which older adults were deemed to be deficient on EF tasks after comparing their performance to a younger normative sample.

MCI Effects: Hypothesis 3.

The third hypothesis attempted to further characterize the neuropsychological profile of MCI by examining whether those with MCI perform more poorly, relative to normal, age-matched controls, on the global EF measure, the saved rotated factor scores, and on the individual tests of EF. It was hypothesized that individuals meeting the present study's criteria for MCI (see Table 1) would perform significantly worse than age-matched controls on EF tasks assessing working memory, behavioral inhibition, and semantic fluency.

The results of the present study suggest that, after controlling for IQ and using education and gender as covariates, the MCI group performed no worse than their age-matched counterparts on the global measure, the saved factor scores, and on all tests of EF. Thus, as a group, individuals with MCI appear to suffer from a relatively specific memory deficit, independent of EF impairment. The hope for early detection in individuals with MCI is to implement some form of intervention (i.e., cholinesterase inhibitors) to prevent or delay the onset of a debilitating, degenerative illness. The present findings raise questions with regard to studies in which individuals, in addition to memory problems, evidence EF deficits when compared to age-appropriate normative samples. Memory impairment accompanied by EF deficits may more accurately identify individuals who are already in the early- to mild-AD stages.

However, it is important to recognize that a lack of significant group differences does not necessarily indicate that the assessment of EF functions in MCI patients is not clinically or heuristically important. A substantial proportion of MCI individuals go on to develop AD, which is characterized by EF deficits, whereas others have a more static or transient presentation of memory difficulties. Perhaps the presence of EF impairment in a subgroup of individuals with MCI has prognostic value with regard to the progression of the disease process. This hypothesis can only be tested through the use of a longitudinal study, which follows individuals with MCI over time. Therefore, along with objective memory impairment and subjective and/or corroborated complaints of memory decline (i.e., by an informant), alternative methods of detection for individuals with MCI may be warranted (i.e., hippocampal atrophy, presence of ApoE 4). Neuroimaging, genotyping, and repeat neuropsychological assessment may be useful in this regard to determine outcome over time.

Alternatively, the lack of significant findings among the OA and the MCI groups may be due to the possibility that EF are not part and parcel of AD and, thus by extension, are not related to MCI. In addition, the various cognitive domains tested for the present study were limited in the sense that these tests were not measures of metacognition, insight, awareness, or drive, all of which are additional functions believed to be involved in executive functioning.

Post-hoc findings: differences between OA and MCI?

Post-hoc analysis indicated that when using a less conservative statistic (ANCOVA), the only significant finding between the OA and MCI groups, while controlling for IQ, education, and gender, was on a test of behavioral inhibition (CMP). Trends were observed on tests of working memory (LNS) and semantic fluency (CATFLU). However, neither the global EF measure nor the saved factor scores were significant.

Thus, when using less conservative statistical analyses, hypothesis 3 is only partially supported when using IQ-controlled measures. However, when non-standardized, non IQ-controlled EF measures were used in the analyses, significant differences did emerge among the OA and MCI groups, which is in support of hypothesis 3. Of interest is the finding that these three tests were those believed to assess domains that are impaired in AD. Numerous studies have reported inhibitory and working memory deficits in individuals with AD. Likewise, studies suggest that category fluency is disproportionately impaired in AD, whereas letter fluency is usually more mildly impaired, if at all, in the early stages (Moscovitch, 1994). Nevertheless, replication is necessary to determine the stability of the present findings.

Significance of findings

The results of the present study suggest that EF is comprised of both unitary and multidimensional components. However, the current findings differ from other studies in that the present findings indicate the construct of EF remains identifiable in a large sample of individuals while controlling for IQ.

Secondly, the current findings suggest the importance of using an age-appropriate comparison group, or normative data, when evaluating older individuals clinically or for research purposes. These results raise concerns about previous findings in which older adults were deemed to be deficient on EF tasks as a result of comparing their performance to a younger normative sample. Moreover, the current findings are consistent with neuroimaging data, which has shown both decreases and increases in brain activity primarily in both frontal and posterior regions in older, as compared to younger, adults (Anderson et al 2000), less asymmetry in activation (Cabeza et al., 2000; Backman et al., 1997), or recruitment of other brain regions different from that seen in young adults (Madden et al., 1999; Cabeza et al, 1997). Reduced brain activity in the performance of cognitive tasks is likely associated with reduced level of functioning (Grady et al., 1995; Cabeza et al 1997; Anderson et al., 2000) and increased activity to the recruitment of other regions, both frontal and posterior, as a compensatory mechanism for decreased ability to effectively carry out some cognitive tasks (Madden et al., 1999; Cabeza et al, 1997). Of note is the finding that older adults may be recruiting the dorsolateral PFC to compensate for reduced activity elsewhere (Rypma & D'Esposito, 2000), specifically when tasks emphasize EF (D'Esposito et al., 1995; 1999).

The current findings also suggest that, when controlling for IQ and using a conservative method of statistical analysis, the MCI group does not differ from their age-matched normal counterparts in their performance on EF tasks. Thus, as a group, individuals with MCI appear to suffer from a relatively specific memory deficit, independent of EF impairment.

Limitations

There were several limitations to this study. One limitation may be related to the method of recruitment of the YA group. Participants were college students who volunteered their time to satisfy a course research requirement, thus reflecting the performance of a circumscribed group of individuals rather than a population-based sample. In addition, the contribution of education with regard to the current findings must be taken under consideration. Most participants in this study were reasonably well educated. The YA group was comprised of undergraduate college students and the OA and MCI groups had a mean education level of 15.96(2.72) and 14.33(2.89) years, respectively.

Another limitation to this study may be the use of an exploratory, rather than a confirmatory factor analytic (CFA) approach or Structural Equation Modeling (SEM), as these latter two methods are fast becoming the statistical method du jour in the hope that they may be more useful in delineating the relationship between purported EF constructs. Finally, this study's small sample size in terms of the MCI group may have limited findings between this group and the OA. In addition, defining objective memory impairment as one standard deviation below the mean of age-appropriate normative data differs from other groups (Petersen et al., 1999), which have defined objective memory impairment as one and one-half standard deviations below the mean. Nevertheless, no significant differences were found between the OA and MCI groups on EF measures despite the fact that the overall MCI group mean on the SRT for the present study fell to nearly two standard deviations below the mean (see Table 1). Perhaps the presence of EF impairment in a subgroup of individuals with MCI has prognostic value with regard to the progression of the disease process (i.e., individuals with a family history of AD, presence of ApoE ε4 genotype). Follow-up of these participants over time is necessary in clarifying the role of EF deficits in MCI.

Summary

The present study examined the degree to which the construct of EF is best conceptualized as a unitary versus a multidimensional construct. Using a factor analytic approach, findings indicated that the initial un-rotated principal component factor accounted for 30% of the variance, suggesting that an identifiable construct of EF exists, independent of IQ. PCA with Varimax rotation resulted in 3 separable components, which accounted for 53% of the variance among all EF measures. These results are consistent with the findings of others (Baddeley, 1998; Duncan et al., 1996; Duncan et al., 1997; Engle et al., 1999; Kimberg and Farah, 1993; Mitsis and Halperin, 2001; Miyake & Shah, 1999; Miyake et al., 2000), which suggest that EF is comprised of both unitary and multidimensional components.

The second finding indicated significant age effects across most EF tests. Specifically, significant age effects were observed on the global EF measure, such that the young adults outperformed the older, normal adults. Among the three saved factor scores, age effects were noted on the factors assessing working memory and behavioral inhibition, but not on the fluency factor. When the 10 IQ-controlled EF measures were examined separately, significant age effects were observed on 5 of the 10 measures. Among the individual tests in which the younger adults outperformed the older adults, those that assess working memory (LNS, TMT, and CPT) and two assessing behavioral inhibition (CMP and WCST-PE) were significant, but those assessing fluency (VERFLU and CATFLU) and two tests of behavioral inhibition (STROOP and TOL) were not. Although no overall measure of speed of information processing (e.g., reaction time) was used per se in this study to examine whether age-related variance remains after controlling for speed, it is notable that three tests among the five were associated with speed (CPT, TMT) and two were not (LNS, WCST-PE). Thus, speed alone may not have contributed to the present findings. Findings also suggest the importance of using an age-appropriate comparison group or normative data when evaluating older individuals clinically or for research purposes.

The third finding of the present study suggests that, when controlling for IQ and using a conservative method of statistical analysis, individuals meeting criteria for MCI performed no worse than their age-matched counterparts on the global EF measure, the saved factor scores, and on all tests of EF. When a less conservative statistic is used, a significant difference emerges between the MCI and normal control groups on one task of behavioral inhibition (CMP). Findings suggest that studies in which executive impairments have been found have included individuals who may be already in the early stages of a dementing process. Follow-up may be necessary to determine whether there may be subtypes of those with MCI who will progress versus those that will not. Neuroimaging, genotyping, and repeat neuropsychological assessment may be useful in this regard to determine outcome over time.

Table 1

MCI Criteria

- Memory complaint
- Memory worse than peers
- Objective memory impairment as assessed by delayed recall of the SRT
- Absence of a neurological or psychotic disorder (e.g., stroke, Parkinson's disease, Huntington's disease, AD, Epilepsy, Traumatic Brain Injury, or Schizophrenia)
- Absence of depression

Table 2

PARTICIPANTS

	Group 1 "YA" N=100		Group 2 "OA" N=52		Group 3 "MCI" N=40	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Age[1]	25.2	9.6	67.9	7.9	72.0	8.6
WAIS-III Vocabulary (standard score)[3]	11.5	3.1	14.1	3.0	11.9	3.4
WAIS-III Block Design (standard score)	10.0	2.8	11.0	2.7	10.0	2.9
WAIS-III Full Scale IQ (estimated)[2]	104.3	13.7	114.8	13.7	105.3	15.1
Education[2]	13.7	0.8	15.9	2.7	14.3	2.9
SRT (delay T score)[3]	N/A	N/A	54.8	7.3	30.8	5.8
Visual Reproductions II[3] (delay raw score)	N/A	N/A	58.8	24.0	32.6	21.4

[1] "Young" < "Old" = "MCI"
[2] "Old" > "Young" = "MCI"; p < .001
[3] p < .001

Table 4

Intercorrelation Among IQ-Controlled EF Measures

	DSB	LNS	TOL	STROOP	VER	CAT	CPT	WCST-PE	TMT	CMP
DSB	1.00									
LNS	.40**	1.00								
TOL	-.10	-.24**	1.00							
STROOP	.00	.11	-.20**	1.00						
VER	.21**	.19**	-.15*	-.00	1.00					
CAT	.11	.37**	-.20**	.06	.40**	1.00				
CPT	-.28**-	-.34**	.18**	-.10	-.05	-.11	1.00			
WCST-PE	-.22**	-.34**	.29**	-.07	-.23**	-.28**	.26**	1.00		
TMT	-.16*	-.46**	.23**	-.14*	-.20**	-.32**	.33**	.34**	1.00	
CMP	-.09	-.30**	.17*	-.20**	-.17*	-.18**	.20**	.22**	.40**	1.00

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