Executive function in daily life: Age-related influences of executive processes on instrumental activities of daily living

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Abstract

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The current study of older adults used structural equation modeling (SEM) to examine the relationships between three executive processes underlying executive function (EF) (inhibition, task-switching, and updating in working memory), and two types of instrumental activities of daily living (IADLs) (self-report and performance-based). Experimental tasks of executive attention from the cognitive psychology literature and self-report or performance-based IADL tests from the medical literature were measured to create the latent constructs of interest (EF and IADL). Confirmatory factor analysis (CFA) was used to examine the construct validity of EF and IADL. Nested two-factor models of EF were compared to a three-factor model of EF. A nested, one-factor model of IADL was compared to a two-factor model of self-report and performance-based items. A three-factor model of inhibition, updating, and task-switching was endorsed in favor of a two-factor model of EF. A two-factor model of self-report and performance-based provided the best fit to the data in the model of IADL. As predicted, when the latent variable relationships were analyzed, executive processes had a significant relationship with performance-based, but not self-report IADLs. In addition, and as predicted from the greater age differences seen on experimental measures of updating and task-switching, updating had a strong and significant relationship with performance-based IADL (.40), followed by task-switching (.22), and inhibition (.10). The results of this study uniquely show a direct relationship between executive processes and IADLs, thus demonstrating that experimental measures of EF have ecological utility. Further, these results point to areas of cognitive rehabilitation that may strategically impact older adults' performance on daily life activities.

Table of Contents

List of Tables

Table

List of Figures

List of Abbreviations

CFA	Confirmatory Factor Analysis
EF	Executive Function
IADL	Instrumental Activities of Daily Living
SEM	Structural Equation Modeling
WM	Working Memory

Chapter 1

Study Aims

The purpose of the current study was to determine the relationships between executive function (EF) and instrumental activities of daily living (IADL) in a sample of community dwelling older adults. More specifically, three executive processes (inhibition, task-switching, and updating) that comprise EF were examined in relation to IADL, and three domains of IADL (home management, financial management, and health and safety). There were two major aims of this study. The first aim was to specify and confirm separate models of EF and IADL based upon existing theory. The second aim was to model the relationships between the executive processes that support EF, and several domains of IADL. A structural equation modeling (SEM) approach was used to pose and test alternative models of these relationships.

Chapter 2

Background and Significance

Executive Function is a broad attentional construct that is thought to be involved in higher-level cognitive tasks performed in the service of a goal. These cognitive tasks may include planning, problem-solving, and adapting behavior in response to changes in the environment (Gazzaniga, 2002; Banich, 2004; Rabbitt, 1997). The neuropsychological construct of EF arose from studies of people with frontal lobe damage who exhibited decreased ability to plan and organize functional, goal-oriented behavior (e.g., Shallice & Burgess, 1991; Duncan, 1986), and are often described as frontal behaviors. Age-related decreases in performance on neuropsychological measures diagnostic of frontal lobe injury (Lowe & Rabbitt, 1997; Shimamura & Jurica, 1994), as well as evidence from functional neuroimaging studies (Cabeza, 2001; Raz & Rodrigue, 2006), support the frontal lobe hypothesis of cognitive aging (West, 1996).

One of the key predictions of the frontal lobe hypothesis of aging is that cognitive processes that are pre-frontal cortex (PFC) dependent should be among the first to decline with advancing age. In line with this prediction, prominent theories of age-related declines in memory have been linked to deficits in executive processes such as inhibitory functions (Hasher & Zacks, 1988), reflective processes (Johnson, Reader, Raye, & Mitchell, 2002; Johnson, Mitchell, Raye, & Greene, 2004), and speed (Salthouse, 1996). An emergent theory is that executive processes such as focus-switching (Verhaeghen & Basak, 2005), updating (Miyake et al., 2000), and task-switching (Salthouse et al, 1998;

Verhaeghen & Cerella, 2002) may be additional areas in which older adults demonstrate differential deficits.

Whereas EF as a neuropsychological construct is a more broad description of complex cognition, EF in cognitive psychology is studied at the level of dissociable executive processes that interact in the service of complex cognition. Early theorists in cognitive psychology adapted the EF construct from neuropsychology to models of working memory as a metaphor of attentional control. One prominent model posits that EF is composed of separate, yet interactive executive processes that operate in the control of working memory (WM) (Baddeley, 1986; 1996). In this standard perspective of WM, a *central executive* controller manipulates the contents of buffers, which hold verbal and visuospatial information.

Executive processes have been studied in younger and older adults under the auspices of the central executive component of WM (Baddeley, 1996; 1997). Recent studies of younger adults have characterized EF as a three-component model that includes *inhibition* of prepotent responses, *updating* in WM, and *task-switching* (Miyake et al., 2000). Other candidate executive processes include *dual-task interference* (Baddeley, 1996), or *time-sharing* (Salthouse, 2005), and activation from LTM into WM (Baddeley, 1996; Miyake & Shah, 1995). The central executive component of working memory remains the least well-studied, despite the important impact it has on cognition. One of the criticisms of standard models of WM has been that the central executive is poorly specified, appearing either as a unified system with multiple functions that share the same resources, or a group of independent yet interactive control processes (Baddeley, 1997; Rabbitt, 1997).

An extension of the idea that simple executive processes give rise to complex cognition, is the idea that executive processes contribute to performance on IADLs. IADLs are real world tasks that may include financial management, medication management, telephone use, shopping for necessities, preparing meals, managing a household, and transporting oneself within the community (Willis, 1996). Successful performance of IADLs confers the ability to age independently in the community. Although a positive relationship between cognition and IADL is fairly well-established (McGuire et al., 2006; Wang et al., 2002), studies that have examined the relationship between EF and IADL have shown that EF may be a better predictor of IADL in older adults than global cognitive measures such as the MMSE (Jefferson et al., 2006; MGinty et al., 2000; Royall et al., 2004; 2005). While more sensitive than global cognitive measures, the neuropsychological tests used in these studies may not be ideal for isolating individual executive processes (Rabbitt, 1997).

One approach that has been successfully used to examine executive processes, as well as relationships between executive processes and IADL in groups of younger and older adults, is structural equation modeling (SEM). SEM uses various types of models to depict theoretical relationships among two types of variables: *measured* variables and *latent* variables. Whereas measured variables are directly observed, latent variables are indirectly represented by a set of measured variables that form a construct. Confirmatory factor analysis (CFA) uses measured variables (indicators) to specify latent variables, e.g., the *measurement model.* When the model is expanded to include the relationships between latent variables of interest, it becomes the *structural model* (SEM).

This approach has many advantages to using traditional correlational regression analyses (Miyake et al, 2000). The advantages of SEM include the use of multiple variables to confirm theoretical models, the incorporation of error terms in the analysis, and the use of multiple groups at multiple levels of analysis (Schumacker & Lomax, 2004). In addition, SEM circumvents many of the problems traditionally associated with neuropsychological EF research, including task-impurity of neuropsychological measures of EF (Burgess, 1997; Rabbitt, 1997) and low test-retest reliability (Banich, 2004; Rabbitt, 1997). For example, the use of latent variables allows the researcher to extract what is common among the tasks used to assess a particular function, thereby circumventing the task impurity problem. In the following two sections, latent variable studies of EF and age-related influences on EF will be reviewed.

Executive Function

There is much recent theoretical debate about the construct validity of EF (e.g., Rabbitt, 1997; Salthouse, 2005), and its unitary, or non-unitary nature (Duncan, Johnson, Swales, & Freer, 1997). Specifically, to what extent do executive processes have convergent validity, or reflect the same underlying attentional construct, while at the same time exhibit discriminant validity, or dissociable patterns of behavior? In addition, is EF a distinct construct? Two views prevail. The first is that EF can be characterized by a few mechanisms (inhibition of prepotent responses, task-switching, and updating), which are separable (e.g., have discriminant validity), yet correlated enough to be a unique construct (e.g., have convergent validity) (Friedman et al., 2006; Miyake et al., 2000). Others argue that a large amount of the variance in EF can be explained by the cognitive abilities, in particular reasoning and perceptual speed (Salthouse, Atkinson, &

Berish, 2003; Salthouse, 2005) and fluid intelligence (gF) (Burgess, 1997; Duncan, 1995; Rabbitt, 1997), and argue that EF has low discriminant validity. These studies used a structural equation modeling (SEM) approach to examine the relationships between cognitive abilities and measures of executive function (e.g., Salthouse, 2005) as well as identify executive processes that are assessed by more complex neuropsychological tests (e.g., Miyake et al., 2000). SEM provides a useful approach for testing construct validity in theoretical models by examining how latent constructs (such as EF) are inferred from sets of measured variables, as well as how multiple latent constructs relate to one another (Schumacker & Lomax, 2004).

Miyake et al. (2000) examined the construct validity of EF in a sample of younger adults, and interpreted his findings in support of EF as a distinct construct. One major goal of the study was to specify the extent to which three target executive processes (updating and monitoring of working memory representations, switching between tasks or mental sets, and inhibition of dominant or prepotent responses) are unitary or separable. These executive processes are discussed in greater detail in separate sections. Confirmatory factor analysis (CFA) was used to specify the degree to which the three postulated latent executive processes are separable or share the same underlying ability or mechanism (e.g., confirm the measurement model). CFA allows researchers to impose a particular factor model on the basis of theoretical considerations and see how well that statistical model fits the data (Schumacker & Lomax, 2004). In this study, a three factor model was compared to two nested models (a one factor and a two factor model), and the three factor model provided the best fit to the data.

Salthouse (2005) interpreted his findings counter to those of Miyake et al. (2000). He assessed the construct validity of EF in a large sample (*n* = 328) of healthy younger and older adults ranging in age from 19 to 93 years of age. The relationship between five cognitive abilities (reasoning, spatial, memory, speed, and vocabulary) and commonly used neuropsychological measures of EF: CLOX (Royall, Cord, & Polk, 1998), Connections Test (Salthouse et al., 2000), Wisconsin Card Sorting Test (WCST; Delis et al., 2001), and Fluency (Letter, Category, Alternating) (Delis et al., 2001), was examined using SEM. Salthouse modeled the five cognitive abilities on each target EF variable (e.g., Fluency), as well as the direct and indirect (mediated through the cognitive abilities) influence of age on each target EF variable. These models assessed the amount of shared variance between the cognitive abilities and each EF variable. The following factor loadings of cognitive abilities on a target EF variable were significant: reasoning on CLOX1 (.49), reasoning on WCST (.47 for number categories and .45 for proportion correct responses), speed on Fluency (.36 for Letter, .35 for Category, and .53 for Alternating), memory on Fluency (.20 for Category and .24 for Alternating), speed on Connections (.44 for Same) and reasoning on Connections (.58 for Same, .54 for Alternating, and .47 for Difference). This pattern of results raises questions about the extent to which EF represents a distinct dimension of individual differences in healthy adults (Salthouse, 2005). However, the cognitive abilities did not explain all of the variance in the EF variables, as can be seen by examining these relationships. There is a moderate amount of unexplained variance in all of the target EF variables (ranging from .42 - .80).

Aging and Executive Function

Across studies of EF and aging that used the SEM approach, mixed results have been found in terms of the construct validity of EF. Based on Miyake et al.'s (2000) results from younger adults, latent variable studies of aging and EF have tested a model with three separable components of EF: shifting, updating, and inhibition of prepotent responses (but see Salthouse, 2003 for an exception). This three-factor model of EF has been replicated in samples of adults ranging in age from 18 to 84 years, with slight modifications (Fisk & Sharp, 2004; Salthouse, 2005). An exception to this pattern of results is noted in Hedden & Yoon (2006), who found that a two factor model (with the shifting and updating components combined) and inhibition, fit the data best in a sample of older adults aged 63-82. Despite moderate correlations in these studies between each of the executive processes of interest (.42-.63 in Miyake et al., 2000; .71-.94 in Salthouse et al., 2003; and .46-.92 in Hedden & Yoon, 2006) (but note Fisk & Sharp, 2004, are the exception, -.20 to .20), models that treat EF as a multi-component construct fit the data better than models that treat EF as a single component. For the most part, correlations among the executive processes for older adults are in the same range as those found in younger adults, although systematic comparisons of separate models of younger and older adults have not been made in the SEM literature.

A secondary focus of this type of research has examined EF as a mediator of the effects of age on the cognitive abilities, as well as any unique effects of age on particular executive processes. Fisk & Sharp (2004) reported that age accounted for 15-20% of the variance in executive processes (updating, inhibition, and task-switching), but that after controlling for processing speed, the only significant relationship with age was task-switching. Whereas age-related impairment in components of EF were observed in all three components, controlling for processing speed removed the age-related variance from updating and inhibition. Crawford et al. (2000) used hierarchical multiple regression to model the relationships between EF, the Digit Symbol Substitution Test (DSST; Wechsler, 1981) commonly used as a measure of speed, age, and three outcome measures: recall, recognition, and serial memory. EF made independent contributions to the variance in free recall and serial recall (but not recognition), over and above that contributed by the DSST, but EF did not make an additional contribution to the age-related variance in free recall or serial recall, as compared to the DSST. These results are in agreement with Salthouse (2005), who found that significant correlations between age and multiple measures of EF (time-sharing, inhibition, and WM) were eliminated after controlling for the cognitive abilities (reasoning, space, memory, speed, and vocabulary), with the exception of Fluency measures (Letter and Category), thought to measure aspects of task-set maintenance, monitoring, and inhibition. These studies show that speed of processing may explain some, but not all of the age-related variance in EF.

In conclusion, the EF construct has been used to describe both complex behavior as measured on neuropsychological tests and more simple executive processes. Despite methodological issues surrounding the measurement of EF, SEM is seen as a useful tool for modeling theoretical relationships between measured and latent variables in studies with younger and older adults. A three-component model of EF has been found to fit the data in both younger and older adults (Miyake et al., 2000; Salthouse, 2003; Fisk & Sharp, 2004) with some exceptions (Hedden & Yoon, 2006). Although the correlations between the separate executive processes are moderate in both age groups, it is unknown whether the pattern of relatedness between executive processes and EF (e.g., the factor loadings) varies in younger and older adults. To establish a better understanding of the relationship between aging and EF, a more detailed look at age differences in each of the three commonly studied executive processes (updating, inhibition, task-switching) was conducted. In addition to being frequently postulated in latent variables studies of EF in younger adults (e.g., Miyake et al., 2000; Salthouse et al., 2003), these executive processes are frequently implicated in theories of aging and WM as possible sources of differential effects of age (Hasher & Zacks, 1988; Verhaeghen & Basak, 2005). Each of these executive processes, as well as how they are thought to be influenced by age, will be discussed in turn.

Inhibition and Aging

The ability to deliberately inhibit an automatic, i.e. *prepotent* response under task demands that require it is commonly labeled an executive process (Logan, 1994; Miyake et al., 2000), largely because it is a voluntary, deliberate act, and the tasks used to measure it have been linked to the frontal lobes (MacLeod, 1991). Tasks commonly used to measure voluntary inhibitory processes include negative priming and Stroop (1935). Negative priming is an index of how well an individual can inhibit attention to a target stimulus that is either the same as or related to a distracting stimulus presented on an immediately preceding trial (Hasher, Stoltzfus, Zacks, & Rypma, 1991; Verhaeghen & De Meersman, 1998a). The Stroop task, which measures the ability to control behavior that conflicts with an automatic response, is often described as a measure of selective attention or interference (McDowd, Oseas-Kreger, & Filion, 1995; MacLeod, 1991; Verhaeghen & De Meersman, 1998b). Although there is some disagreement about the voluntary inhibitory nature of negative priming (see Miyake et al., 2000), it has been used extensively to measure inhibitory processes in attention in studies that compare younger and older adults (e.g., Hasher & Zacks, 1988; Hasher, Stoltzfus, Zacks, & Rypma, 1991).

One prominent explanation of age differences in WM has been the inhibitory deficit hypothesis (Hasher & Zacks, 1988), which suggests that age differences in WM capacity result from a decline of inhibitory function with increasing age. According to this theory, defective inhibition either causes irrelevant information to enter into working memory, consequently limiting its functional capacity, or causes irrelevant material within working memory not to be suppressed, resulting in distraction from the task. While earlier research (on negative priming) supported the inhibitory deficit hypothesis of aging (Hasher, Stoltzfus, Zacks, & Rypma, 1991; Kane, Hasher, Stoltzfus, Zacks, & Connelly, 1994; McDowd et al, 1991), more recent research has provided mixed evidence, generally converging on equivalent age differences on a number of tasks that are purported to measure inhibition (Gamboz, Russo, & Fox, 2002; Verhaeghen & De Meersman, 1998a; Verhaeghen & De Meersman, 1998b; Verhaeghen & Cerella, 2002).

One such example of mixed results comes from meta-analytic studies of negative priming, a task that measures how well a person is able to inhibit a response to a target that was a distractor on the previous trial. Verhaeghen & DeMeersman (1998a) found some support for an age-related inhibitory deficit in a meta-analytic review of studies of aging and identity and location negative priming. Identity priming refers to negative priming tasks in which the response is related to the identity of a stimulus (such as naming a pictured object or reading a letter aloud) and location priming refers to negative priming in tasks in which the response is related to the location of a stimulus (such as pressing a key on the keyboard corresponding to the location of a particular stimulus). An inhibitory deficit of aging would predict less slowing for older adults than younger adults when responding to a target that was a distractor on the previous trial, resulting in smaller negative priming effects for older than younger adults. The overall negative priming effect for older adults (*d* = .13) was marginally significantly different from younger adults (*d* = .27), $p < .10$, but when identity and location negative priming were analyzed separately, the effects of age were greater only on location negative priming. This evidence was interpreted in favor of the inhibitory deficit of aging. In contrast, in an updated meta-analysis by Gamboz et al. (2002), the conclusion that identity negative priming is reduced in older adults was unsupported. Using meta-analytic procedures comparable to Verhaeghen & De Meersman (1998a; 1998b), their results demonstrated that the negative priming effect for older adults (*d* = .18) did not differ significantly from younger adults (*d* = .23). Compared to Verhaeghen & De Meersman (1998a), this study had increased power (16 additional studies, with the results collapsed across studies of both identity and location priming). Assuming that inhibitory processes support the negative priming effect, these results are at odds with the inhibitory deficit theory (Hasher & Zacks, 1998; Zacks & Hasher, 1994).

As a measure of age-related inhibitory deficits, the Stroop (1935) interference effect also appears to show age equivalence. The Stroop task been used extensively to measure selective attention, in particular the external (automatic) versus internal (executive) control of behavior (see Macleod, 1991, for a comprehensive review). In the most commonly used version of the Stroop task, participants report the color in which words, or word-like stimuli, are presented. When the color and word are in conflict, such as when the word GREEN appears in red, color naming is slower and less accurate than when the word is unrelated to the color (e.g. THINK, or XXX, in red), or when the color and word match (e.g., GREEN in green). The response slowing to conflict, or "incongruent", stimuli is known as the *Stroop effect* or *Stroop interference.* Stroop interference is most commonly thought to represent the failure of a goal ("ignore the word") to control behavior in the face of a conflicting habitual response (reading the word). Results from a meta-analysis of 20 experiments (from 14 studies) on the Stroop effect in younger and older adults demonstrated that both younger (d = 2.04) and older (d = 2.17) adults showed large, but equivalent, effects of Stroop interference (Verhaeghen & De Meersman, 1998b).

In conclusion, meta-analyses of aging and inhibition find little or mixed support for an inhibitory deficit hypothesis of aging (Gamboz et al., 2002; Verhaeghen & De Meersman, 1998a; Verhaeghen & DeMeersman, 1998b; Verhaeghen & Cerella, 2002). Additional evidence from studies of identity negative priming published since Verhaeghen & De Meersman (1998a) also point to small or no age differences (Gamboz, 2000; Gamboz, Russo, & Fox, 2000; Kieley & Hartley, 1997; Little & Hartley, 2000), although see Butler & Zacks (2006) for findings of greater age differences on the anti-saccade task, which is thought to tap reflexive aspects of inhibition. Meta-analytic and experimental studies of age differences in Stroop interference also do not support the inhibitory deficit hypothesis of aging (Burke, 1997; Little & Hartley, 2000; McDowd, 1997; Verhaeghen & De Meersman, 1998b), but there may be exceptions (Davidson, Zacks, & Williams, 2003).

Task-Switching and Aging

Task-switching is thought to represent a separate executive process, whereby shifting attention back and forth between multiple tasks, operations, or mental sets (intentions) may facilitate completion of a task operation (Allport, Styles & Hsieh, 1994; Rogers & Monsell, 1995). For example, switching or redirecting of attention between aspects of storage and processing is most likely necessary for successful WM functioning (Baddeley, 1996). In a task-switching paradigm, the time taken to complete a sequence of trials when participants do or do not switch between different tasks on successive trials is compared. Generally, in each set of tasks in a switching paradigm, two different but equally simple decisions can be made on the same stimuli, and participants (in the switching condition) are cued either predictably beforehand (e.g., "on every second trial, change switching rules"), or unpredictably during the task to change decision rules (e.g., with an external cue such as "use decision rule B"). A commonly used task-switching paradigm, the *alternating runs paradigm* (developed by Monsell, 1995) uses two tasks: classifying a digit as odd or even, and classifying a letter as a consonant or a vowel. Each stimulus consists of a pair of characters (a letter and a number) presented side by side in one of four quadrants. Participants perform either the letter or the classification task based upon the location of the stimuli.

The focus of current research on task-switching in younger adults has been on the component processes involved in the costs of switching between tasks as well as the change in each component under different conditions (e.g., the effect of varying the response to stimulus interval (RSI), or cue type (predictable or unpredictable)). Across most experimental studies of task-switching in younger adults, two types of switch costs are measured, the *local* switch cost and the *global* switch cost. The local switch cost is typically measured by taking the difference in RTs between switch and non-switch (repeat) trials within a block (using the alternating runs paradigm of Rogers and Monsell, 1995). This is thought to be an indicator of the executive process associated directly with the switch. The global switch cost (also the mixed-list cost, Meiran, 1996) is the difference between RTs in blocks with only single tasks and RTs on repeat trials in blocks where the participant has to switch between tasks (e.g., no-switch RTs minus single task RTs). The global switch cost indicates the set-up costs associated with maintaining and scheduling two mental task sets (Verhaeghen & Cerella, 2002) and also may measure the uncertainty associated with expecting or preparing for a switch (Salthouse, Fristoe, McGuthry, & Hambrick, 1998)

Several explanations for switch costs have been set forth, some of which call into question the degree to which task-switching is an executive control process or an automatic process. For instance, some have emphasized the degree to which switch-costs are a consequence of proactive interference, or the persisting activation of processes related to the first task (Allport, Styles, and Hsieh, 1994; Wylie and Allport, 2000). This persisting activation of the previous task set dissipates when participants have greater opportunity for advanced preparation (such as larger RSIs), but does not disappear completely. An alternative explanation, proposed to account for the remaining RT costs observed at long RSIs of over 1000 ms, is that lowered (local) switch costs must involve a prospective process of *task set reconfiguration, or preparatory reconfiguration* prior to performance on the new task (Meiran, 1996; Rogers and Monsell, 1995; Monsell, 2003). In order to account for the observation that neither the experimental paradigms of Allport et al. (1994) or Rogers and Monsell (1995) distinguish equivocally between passive dissipation of the previous task set on the one hand and limited preparatory reconfiguration on the other hand, still others have proposed a three component model of task-switching (Meiran, Chorev, and Sapir, 2000; Monsell, 2003), including a dissipating component that does not reflect cognitive control, a preparatory component which most likely reflects cognitive control (though see Rogers & Monsell, 1995 for alternative explanations), and a residual component (the remaining RT cost associated with the switch after preparatory reconfiguration) indicating control failure.

Studies of task-switching and aging have also focused on understanding its component processes. The results of studies of aging and local task-switching are inconclusive. Generally no age-related deficits are found in local task-switching. For instance, in studies that used an alternating runs paradigm, age effects on the local task switch were equivalent with practice and longer RSI's (1200 ms) (Kramer, Hahn, & Gopher, 1999; Kray & Lindenberger, 2000), and with both verbal and figural stimuli (Kray & Lindenberger, 2000). One exception is Salthouse, Fristoe, McGuthry, and Hambrick (1998), who found larger age differences in RTs on switch trials than on baseline or pre-switch trials (all age x trial type interactions were statistically significant). The finding of a differential effect of age on the local task switch, although unusual, may possibly be explained by the 0 ms cue to target interval (participants alternated between two tasks (More/Less or Odd/Even), and external switch cues were presented at the same time as the stimuli (e.g., "start with more/less" appeared simultaneously with two, side by side, digits). The above explanation would concur with findings that smaller CTIs exacerbate age differences in the local switch cost (Kray & Lindenberger, 2000).

In contrast, differential effects of age are found on the global task switch (Kramer, Hahn, & Gopher, 1999; Kray & Lindenberger, 2000; Mayr & Liebscher, 2001; Verhaeghen & Cerella, 2002). In the alternating runs paradigm, greater age differences in the global switch cost are maintained with practice, increasing RSI, and type of stimuli (verbal and figural) (Kramer et al., 1999), whereas they increase when older adults have to maintain two task sets endogenously (predictably) (Kramer et al., 1999).

Overall, these studies show that the effects of age are greater on the global than the local task switch. The effects of age on the local task switch, but not the global task switch, are exacerbated with decreases in the amount of practice, the response to stimulus interval, the cue to target interval, and the unpredictability of the cue, in most cases. Age differences in the global task switch are increased when the endogenous switching demands of the task increase (Kray & Lindenberger, 2000; Salthouse et al., 1998), and this makes sense in light of findings that greater age differences are found in WM when older adults have to actively coordinate and maintain two task sets in a readily accessible state (Miyake & Shah, 1995).

Updating and Refreshing in Aging

Cognitive processes that maintain and manipulate information on-line, e.g., working memory (WM) (Baddeley, 1986), are critical for all higher-order cognition. Depending on the complexity of the WM task, multiple executive processes may be involved. It has been suggested that WM tasks include recycling information, updating information, and evaluating whether a test probe meets criteria, among others (Raye, Johnson, Mitchell, Reeder, and Greene, 2002). Two candidate executive processes that have been studied in relation to age are *updating*, and *refreshing*, although the updating-related findings are not as consistent with regards to age differences as the refreshing-related findings.

Updating requires monitoring and coding information for task relevance and revising items held in WM, by replacing old, no longer relevant information with newer, more relevant information (Morris & Jones, 1990; Jonides & Smith, 1997; Smith & Jonides, 1999). One primary example of updating occurs in the N-back task, where an item on the current trial is compared to an item held in WM, in an ongoing manner. In the N-back task, the item currently in the Nth position back will need to be overwritten with the item currently on the screen. Information is actively monitored for redundancy, and replaced with new, task-relevant information in a sequential manner.

Few experimental studies of aging have attempted to isolate the updating component of WM. Verhaeghen & Basak (2005), used an identity version of the N-back task, where updating was necessary only when the item presented in the Nth position back differed from the currently visible item. The updating cost was analyzed as the difference between RTs on "Yes" versus "No" responses. The age x updating interaction reached significance, but did not survive the log transformation used to correct for proportional slowing. In contrast, Van der Linden, Bredart, & Beerten (1994) found that age differences were greater in a running memory task, when larger set sizes were used. The running memory task also measures the ability to discard old items and register new ones in a continuous manner, requiring participants to watch strings of consonants whose lengths are unknown, and then to recall serially a specific number of recent items. In Experiment 2, when participants were shown lists of 6, 8, 10, and 12 consonants at a rate of 1 sec each and asked to recall the last 6 presented items, older adults showed an age x list length interaction, thought to indicate an age-related deficit in updating.

Age differences are more consistently found in a related but distinct process, refreshing. Refreshing is a simple executive process that involves briefly thinking of a just-activated thought or percept in order to selectively augment (foreground) and/or extend (maintain) activity associated with a recently activated representations (Raye et al., 2002; Johnson, Raye, Mitchell, Greene, Cunningham, & Sanislow, 2005; Raye, Johnson, Mitchell, Greene, and Johnson, 2007). Refreshing can be conceptualized as both a manipulation and a maintenance process in the sense that it selects a particular representation relative to others as well as extends the availability of an active representation (Raye et al., 2007). In the refreshing paradigm, participants read words aloud as they are presented one at a time on the computer screen (at a 2.5 sec rate) in three, inter-mixed conditions. Sometimes a word is the same as the previous word (a repeat item), and sometimes a dot is presented, signaling the participant to think of the last word presented and say it aloud again (a refresh item). Verbal response times are compared for items presented once (read items), repeat items, and refresh items. This is usually followed by a surprise recognition test, in which participants indicate whether they have seen a previously presented word or not.

Support for the refreshing mechanism comes from studies that show functional neural dissociations within the refreshing paradigm (e.g. between brain activity on read, repeat, and refresh trials) and from other reflective mental processes, such as rehearsal. First, a functional dissociation of left anterior (process initiation-initiating an action or response) and dorsolateral PFC (refresh-related activity) has been replicated multiple times (Raye et al., 2002; Johnson et al., 2004). Further support for the refreshing mechanism comes from its conceptual and neural dissociation from rehearsal (Johnson, et al., 2005; Raye et al., 2007). Whereas refreshing is a discrete, briefer act of reflective attention directed towards a current representation, rehearsing typically involves one or more items cycled through several times over several seconds (Baddeley and Hitch, 1974). In addition, refreshing causes greater activation in left dorsolateral PFC, whereas rehearsing causes greater activation in ventrolateral PFC. They also show different patterns of functional connectivity with other areas of the brain, providing further support that these are distinct cognitive processes.

Two potential sources of age differences in WM are updating and refreshing. Age differences in updating are not well-replicated, in large part because of the variety of ways in which it is measured. For instance, experimental studies have isolated the updating process using traditional WM tasks such as N-back and running memory with mixed results (Miyake et al., 2000; Van der Linden et al., 2004; Verhaeghen & Basak, 2005). In addition, correlational analyses have measured the updating process with higher level measures of WM (e.g., complex reading and computation span tasks (Fisk & Sharp, 2004) and backwards digit span (Hedden & Yoon, 2004)), finding a positive correlation between updating and recollection in older adults. Age differences in refreshing are better replicated than age differences in updating in WM. Older adults are disproportionately slower on saying the previous word on refresh trials. Younger adults, but not older adults, show a long-term recognition memory benefit for refreshed items relative to single presentation items (Johnson et al., 2002; Johnson et al., 2004). This is taken as evidence that older adults have a decreased ability to maintain activation of just-activated, task-relevant representations.

Instrumental Activities of Daily Living in Aging

Instrumental activities of daily living (IADL) are a group of tasks performed in daily life that are essential to independent community living. IADL, broadly described as the ability to manage one's affairs and property (Katz et al., 1969; Lawton & Brody, 1969), is distinguished from basic activities of daily living (BADL), which include routine self-care activities such as the ability to eat, dress and bathe oneself independently. Traditional IADL tasks included managing money, using the telephone, taking medications, traveling, shopping, preparing meals, doing laundry, and housekeeping (Lawton & Brody, 1969). The limited research on cognition and IADL shows deficits in four main IADL activities that have been correlated with cognitive impairment, including telephone use, transportation use, taking medications, and managing finances (Barberger-Gateau et al., 1992; Bell-McGinty, Podell, Franzen, Baird, & Williams, 2002). Although there is a broad consensus as to the activities needed for independent community living, a wide variety of number and type of activities are included in more recently developed IADL measures (Law et al., 2001; Willis, 1996), including the ability use transportation to access the community.

Several important factors contribute to the choice of IADL assessment. The first is the source of the information. Measures of IADL may be self-report, proxy (caregiver report), or direct observation (performance-based). In healthy older adults, scores on self-report and objective ratings are modestly correlated, but overestimation on self-report measures is more common (Albert et al., 2006; Willis, 1996). Second, the measurement scale of the IADL assessment may evaluate the level of dependence of the task (e.g., Lawton & Brody, 1969) or difficulty performing the task (e.g., Fisher, 1993). Difficulty scales have a tendency to yield higher estimates of disability than scales that measure dependency (Law et al., 2001). Third, either type of scale may measure competence, or what the individual feels he or she is capable of doing, versus what he or she actually chooses to do. For instance, competence represents older adults' potential or capacity for making decisions necessary for the care and maintenance of themselves and their property, but this may involve actively choosing to delegate certain responsibilities to others (Willis, 1996).

Traditional measures of IADL do not discriminate among groups, such as the well elderly or young and middle-aged adults, with intact competence in daily living (Law et al., 2001). However, traditional measures of IADL are sensitive to functional changes in particular groups of non-demented older adults that report a higher incidence of IADL, including those who are older, less educated, and female (Albert et al., 2006). In the study by Albert et al., participants who were above eighty years of age, had less than twelve years of education, and were female, were twice as likely to report IADL impairment. In line with these results, there is relatively modest decline in performance on cognitively complex everyday tasks during the 60's, but steeper patterns of normative decline are found in the late 70s and 80s (Willis, 1996). Persons with no diagnosed disorder may have trouble with cognitively complex daily activities for a number of reasons, including lower self-efficacy beliefs (Willis, 1996; Hess, 2005), and education (Jefferson, Paul, Ozonoff, & Cohen, 2006; Mcguire, Ford, & Ajani, 2006). Additionally, older adults who are at risk for declines in functional health status (for instance those who have controlled high blood pressure and Type II diabetes), are more likely to have IADL impairment (Wang, van Belle, Kukull, & Larson, 2002; Royall, Palmer, Chiodo, & Polk, 2004). Older adults who show a range of variability in age, gender, education, and health status are more likely to show measureable performance decrements on IADL tasks.

Aging, Cognition, and Instrumental Activities of Daily Living

Cognitive function is an important influence on the day-to-day function of older people and an important predictor of functional change in older adults. Cognitive function is a description of the cognitive abilities that are assessed with global cognitive measures such as the Mini-Mental Status Examination (MMSE) (Folstein, Folstein, & McHughes, 1975), a widely used screening tool. The cognitive abilities measured by the MMSE include recall, orientation, attention, and language. Recent longitudinal studies of community-dwelling older adults over age 65 (McGuire et al., 2006; Wang et al,, 2002) and older adults living in Continuing-Care Retirement Communities (CCRCs) (Royall et al., 2004) have found that cognitive function is a significant predictor of self-reported functional status on various self-report measures of IADL, and that several important variables may moderate this relationship.

While decreases in global cognitive status are indicative of decreases in IADL status (Dodge et al., 2005; McGuire et al., 2006; Wang et al., 2002), EF (as measured by neuropsychological tests) may be a better predictor of IADL status in older adults (Jefferson et al., 2006; McGinty et al., 2000; Royall et al, 2004; 2005). This may especially be true in older adults who show a range of normal cognitive variability (Bell-McGinty et al., 2002) and/or health status (Wang et al., 2002). Royall et al. (2004) compared the contributions of global cognitive status and EF to IADL in a 3 year longitudinal study of 547 non-institutionalized older adults. Executive function (measured by the Executive Interview (EXIT25; Royall, Mahurin, & Gray, 1992), a standardized clinical assessment of frontal dysfunction), was more sensitive to cognitive impairment than global cognitive status (measured by the MMSE). In addition, longitudinal change in EXIT25 was a significant predictor of IADL (measured by the Older Adults Resources Scale (OARS; Fillenbaum, 1978), a structured self-report measure), whereas change in MMSE was not.

Further support for the relationship between EF and IADL comes from studies that use extensive batteries of neuropsychological tests to predict IADL performance. Jefferson et al. (2006) found that inhibition as measured by the DKEFS Color-Word Interference Test (Delis, Kaplan, & Kramer, 2001) was a significant predictor of self-reported IADL in a group of older adults with a history of cardiovascular disease. A questionnaire that assessed level of dependence was administered to primary caregivers as the measure of IADL (Lawton & Brody, 1969). Using a similar approach, McGinty et al. (2000) found that the Trail-Making Test (Reitan & Wolfson, 1985) and the WCST (Delis et al., 2001), were the only significant predictors of IADL, after controlling for age, sex and education in a group of non-demented older adults (n = 27). IADL in this study was assessed with the Independent Living Scales (ILS) (Loeb, 1996), a performance-based measure that allows for objective assessment of functional skills through direct observation.

While there is support that the neuropsychological construct of EF can predict IADL function in older adults, caution should be applied in generalizing these results across populations of older adults. For instance, the samples of older adults in the studies reviewed here varied in a number of ways, including medical diagnosis (e.g., Jefferson et al., 2006), and level of independence (e.g., Royall et al., 2005; 2006). In addition, while these studies demonstrated some overlap in choice of screening measures for global cognitive status, no two studies used the same neuropsychological assessments of EF or IADL. The choice of type of IADL assessment may be especially important, as some research has shown that performance-based measures may be more reliable than self-report measures (Law et al., 2001). Additionally, there are many other factors (including health risk, SES, and education) that could mediate these relationships, and this varies by study. For instance, McGinty et al. (2000) controlled for age, sex, and education, whereas Royall et al. (2005; 2006) controlled for baseline co-morbid disease, level of care, baseline disability, and baseline EF. Finally, the construct validity issues surrounding the measurement of EF with neuropsychological tests reviewed earlier in the paper apply here as well.

Chapter 3

The Current Study

The current study of latent variables in older adults had two major goals. The first was to examine the construct validity of EF and IADL. The second was to understand the relationship between EF, executive processes (inhibition, task-switching, and updating), and IADL. Although relationships between EF and IADL have been examined in a few studies using neuropsychological measures, the relationship between executive processes and IADL is unexplored. Much of the related literature examines a wide range of aging persons with large health-related variability, but excludes persons diagnosed with dementia or mild cognitive decline. This study will examine the relationship between EF and IADL in a more representative sample of normally aging older adults than has been previously examined, with higher variability on characteristics such as age, gender, and self-reported IADL status.

Construct Validity of EF and IADL in Older Adults

Question 1. The first major goal of this study was to specify the constructs of interest (EF and IADL) in older adults. Under this rubric, two questions were addressed. First, what is the underlying factor structure of EF in older adults? The construct validity of EF has been the subject of much debate in the literature (e.g., Miyake et al., 2000; Salthouse, 2005; Salthouse et al., 2003). In younger adults, the construct validity of EF has been tested using a three-factor model consisting of inhibition, updating in WM, and task-switching (Miyake et al., 2000), but this has not been replicated in older adults. Mixed findings in older adults include two, three, and four-factor models using a variety of executive processes (Hedden & Yoon, 2006; Salthouse, 2005). The current study was designed to address some of these limitations in an aging study, by using experimental measures to create latent variables of the three executive processes (inhibition, task-switching, and updating), and then assessing their convergent and discriminant validity.

Hypothesis 1. Although some evidence exists for dedifferentiation (less specificity) of pre-frontal cognitive mechanisms in aging (Rajah & D'Esposito, 2005), there is little evidence to suggest exactly how models of younger and older adults might differ in this respect. For instance, the latent variables of inhibition, task-switching, and updating might lack discriminant validity in older adults, and combine to form a two-component model of EF, versus the three-component model in younger adults shown by Miyake et al. (2000). In addition, the pattern of factor loadings of executive processes on EF may vary. For example, task-switching, might have a higher loading on EF than either inhibition or updating. This type of result might be predicted from more reliable findings of greater age differences in components of task-switching (e.g., Kramer et al., 1999; Kray & Lindenberger, 2000), than inhibition or updating.

Question 2. Second, it was necessary to gain a better understanding of the IADL construct. Is IADL better represented by two distinct factors, self-report and performance-based assessments, or one combined factor? Two types of IADL measures, self-report and performance-based, are used typically. Performance-based assessments may provide a more accurate assessment of individual differences in cognitively complex tasks (Willis, 1996), whereas others have argued that self-report measures may be more contextually valid (Hess, 2005). Currently, there is not enough evidence for using one type of measure in favor of another (Law et al., 2001). Therefore, the study assessed which type of test might be most valid.

Hypothesis 2. Based on prior findings that performance-based and self-report measures may elicit quantitatively different information (Albert et al., 2006; Willis, 1996), it is hypothesized that IADL will be best represented by a two-factor model.

Relationships Between EF and IADL in Older Adults

Question 1. The second major goal of this study was to assess the relationship between EF and IADL. Under this second goal, there were two related questions. First, which executive processes are the best predictors of overall IADL in older adults? Experimental studies of aging and executive processes suggest that older adults show greater decreases in components of task-switching (Verhaeghen & Cerella, 2002), and in the updating and refreshing components of working memory (Johnson et al., 2002), but not inhibition (Verhaeghen & de Meersman, 1998a; 1998b). In partial agreement, neuropsychological tests of inhibition and task-switching have been found to predict IADL function (Bell-McGinty et al., 2002; Jefferson et al., 2006).

Hypothesis 1. Based on these conflicting results, it is difficult to predict which executive processes might be the best predictors of IADL. Using experimental tasks to measure executive processes, and relating them to IADL, may better isolate these relationships in older adults. It is hypothesized that the task-switching and updating processes will have a stronger relationship with IADL than inhibition.

Question 2. The last question was designed to assess how the relationship between EF and IADL might differ based upon how the IADL construct is specified. Is EF a better predictor of self-report, or performance-based IADLs? It has been suggested that performance-based IADL assessments may be more accurate than self-report measures, but this varies based on the older adult sample. Normally aging older adults have a tendency to overrate their IADL performance (Albert et al., 2006; Willis et al., 1996). Older adults with cognitive impairment may overrate their performance more so than older adults without cognitive impairment on self-report measures (Barberger-Gateau et al., 1992), but older adults with a physical impairment, or depression, have a tendency to underestimate their performance (Willis, 1996).

Hypothesis 2. Based on evidence from normally aging older adults, it is hypothesized that executive processes assessed with experimental tasks may show a stronger relationship with performance-based than self-report measures, and that older adults may overestimate their IADL performance on self-report measures compared to performance-based measures.

Chapter 4

Method

Participants

Participants included 75 community-dwelling older adults (ages 60-90) from an existing database recruited through local advertisements and paid ten dollars per hour for their participation (mean age = 72 years; mean years of education = 16.2 years).

Eligibility requirements for all participants included normal or corrected-to-normal vision and reports of good to excellent health on a health-screening questionnaire. Participants were excluded if they reported a history of neurological or psychiatric disorders, learning disability, major illnesses that may affect their cognitive function, or use of psychoactive medications. Older adults in the database received an extensive battery of standardized neuropsychological tests: The Trail Making Test (A and B), the vocabulary subtest of the Wechsler Adult Intelligence Scale-III, subtests for the Wechsler Adult Memory Scale-III (Logical Memory I and II, Visual Reproduction I and II, Verbal Pairs I and II, and Mental Control), subtests of the Wechsler Adult Intelligence Scale-III (Digit Span Forward and Backward, Arithmetic, Information, Comprehension), the Control Oral Word Association Test (FAS), the California Verbal Learning Test, and the Wisconsin Card Sorting Test.

Materials: Inhibition

Stroop. The Stroop task (1935) was adapted for administration on the computer. Participants were instructed to indicate the color of a stimulus as quickly as possible on each trial with a key press. In the neutral trials, a string of X's were presented in one of six colors (red, green, blue, orange, yellow, or violet). In congruent trials, a color word was presented in the same color (e.g., BLUE in the color blue), and in incongruent trials, a color word was presented in a different color (e.g., BLUE in the color red). Participants received 10 sample, 15 practice, and 100 test trials, fully randomized. The proportion of trials was as follows: 20 congruent, 40 neutral, and 40 incongruent. The dependent measure used in the analysis was the RTs for correct incongruent trials.

Anti-Cue. In the Anti-Cue task (after de Jong, 2001; Salthouse et al., 2003), the participant's goal is to indicate the location of a briefly presented target stimulus, after ignoring a cue presented either on the same side as or the opposite side as the target stimulus. Stimuli in this task were the letters P and Q, and the responses consisted of presses of those keys. A fixation cross appeared for 1000 ms before each trial. The target stimulus was presented for 75 ms, but 350 ms before each stimulus an asterisk flashed (50 ms on, 25 ms off, 50 ms on), either on the same side as the target stimulus or the opposite side. A visual mask (the # symbol) was presented immediately after the stimulus in the location of the possible stimulus on both sides of the display and remained until after a response was made. Participants received 10 sample, 10 practice, and 80 test trials, fully randomized. The proportion of trials was split equally between valid and invalidly cued. The dependent measure used in the analysis was the RTs for correct incongruent (flash and target on different sides) trials.

Stop-Signal. In the Stop-Signal task (after Logan, 1994; Miyake et al., 2000; Salthouse et al., 2003), participants are required to inhibit a response to a visually presented stimulus on trials immediately followed by an asterisk. Stimuli in this task were the letters *X* (to which the response was a press of the “*Z*” key) and *O* (to which the response was a press of the “*/*” key). Each trial began with a fixation cross (for 1000 ms), followed 500 ms later by a target stimulus (for 50 ms). On 25% of the trials, an asterisk occurred (for 100 ms) immediately following the target stimulus, with equal probability 200, 400, or 600 ms after the target stimulus, indicating that the participant was to refrain from making any response to the previous target stimulus. Participants received 15 sample, 15 practice, and 100 test trials, fully randomized. The dependent measure was the proportion of incorrect responses on the stop trials.

Materials: Updating and Refreshing

Refreshing. The Refreshing paradigm (adapted from Johnson et al., 2002). assesses how long it takes for a person to think of a just-previously presented word. Stimuli in this task consisted of common, one to two syllable words. On all trials, a word appeared in the center of the computer screen for 1550 ms. On "repeat" trials, the initial word was followed 450 ms later by the same word, and on "refresh trials", the initial word was followed by a question mark. In the repeat trials, participants were instructed to indicate a repetition with a keypress, and in the refresh condition, the participant was instructed to think of (refresh) the just-preceding word, and indicate with a keypress if the word contained either one, or two syllables. Participants received 10 sample, 10 practice, and 100 test trials, fully randomized. Half of the trials were repeat trials and half were refresh. The dependent measure was the difference between RTs for correct repeat and refresh trials.

N-Back. In the N-Back task (adapted from McElree, 2001), participants judge whether or not the identity of a current stimulus is identical to the item that was presented

N items back (N in this task varied from 1 to 2). After the identity judgement is made, the item currently in the Nth position needs to be overwritten, or updated with the item currently on the screen. Stimuli (numbers) were presented continually one at a time in the center of a computer screen every 2000 ms, and participants indicated "Yes" (identical) or "No" (not identical) with a keypress. As soon as a keypress was made, a new stimulus appeared. Participants received 10 sample, 15 practice, and 60 test trials, fully randomized. Half of the trials were yes judgements and half were no. The dependent measure was the proportion of incorrect responses when $N = 1$.

Letter-Memory. In the Letter-Memory task (adapted from Morris & Jones, 1990; Miyake et al., 2000), participants recall the last four letters presented in a list. Several letters from a list were presented serially for 2000 ms per letter in the center of the computer screen. List lengths (5, 7, 9, or 11) occurred with equal frequency and varied randomly across trials. Instructions required participants to rehearse out loud the last four letters by mentally adding the most recent letter, dropping the fifth letter back, and then saying the new string of four letters out loud (Miyake et al., 2000). Participants received 10 sample, 10 practice, and 48 test trials, fully randomized. The dependent measure was the proportion of letters recalled incorrectly.

Materials: Task-Switching

Number-Letter task. In the Number-Letter task adapted from Rogers & Monsell (1995), a number-letter pair (e.g., 8H) is presented in one of four quadrants on the computer screen. Particpants are instructed to make an odd/even judgement when the number-letter pair is presented in the upper two quadrants, and a consonant/vowel judgement when the number-letter pair is presented in the lower two quadrants. In the first block, the number-letter pair was presented in the upper quadrant (no-switch odd/even judgement). In the second block, the number-letter pair was presented in the lower quadrant (no-switch consonant/vowel judgement). In the third block, the number-letter pair was randomly placed in either the upper or the lower quadrants. Responses (odd/even or </>) were self-paced and made with a keypress. The next stimulus was presented 150 ms after the response. Participants received 10 sample and 10 practice switch trials before they started the test. Next, they completed 50 test trials in each of the two no-switch blocks, and 100 test trials in the switch block, fully randomized. The dependent measure was RTs on correct switch trials.

Local-Global. In this version of the Local-Global task (adapted from Navon, 1977; Miyake et al., 2000), a geometric figure called a Navon figure, in which the lines of the global figure (e.g., circle, X, triangle, and square) were composed of much smaller, local figures, was presented in the center of the computer screen. Depending upon the color of the figure (either blue or black), participants were instructed to make a keypress corresponding to the number of lines (1 for a circle, 2 for an X, 3 for a triangle, and 4 for a square) in the global, overall figure if it was blue, or the local, smaller figure if it was black. Participants received 10 sample, 15 practice, and 100 test trials. Responses were self-paced and separated by a 500 ms response-to-stimulus interval. The trials were randomized, with the constraint that half of the trials required a switch from local to global features or from global to local features. The dependent measure was RTs for correct trials requiring a switch in mental set when the color of the stimulus changed.

More-Less and Odd-Even. In this task (adapted from Salthouse, Fristoe, & Guthry, 1998), single digits were presented one a time in the center of the computer screen for 2000 ms, and participants were asked to make a More/Less or an Odd/Even judgement, indicated with a button press (the “Z” key for odd and the “X” key for even; the “<” key for less than and the “>” key for greater than). When the number was blue, participants indicated if that number was odd or even, and when the number was red, participants indicated if that number was less than or more than the number that preceded it. Participants completed 10 sample, 20 practice, and 110 test trials. Trial type was randomized, with an equal number of switch and no-switch responses. The dependent measure was the RTs for correct trials on which a switch between more/less or odd/even was required.

Materials: Instrumental Activities of Daily Living

Independent Living Scales (ILS). The ILS (Loeb, 1996) is an individually administered and objective assessment of ability to perform IADLs. The ILS contains five subscales that assess daily living skills: Memory/Orientation, Managing Money, Managing Home and Transportation, Health and Safety, and Social Adjustment, with scores for individual items ranging from 0 to 2. Higher ILS scores are associated with better functional ability. The five subscale scores are combined to obtain a standard score that represents an individual's ability to live independently. Cut scores are provided as a means of establishing criterion validity with adults aged 65 and older who are living independently, semi-independently, or dependently. The ILS contains 68 items across all five subtests and takes approximately 45 minutes to administer. Three of the subscales (Managing Money, Managing Home and Transportation, and Health and Safety) were administered in this experiment. Items from each of the three subscales were combined into parcels (Money, Home, Health), summed, and then transformed into z-scores to minimize scaling differences between the threes tests of IADL (details of this procedure are described under item parceling for IADL).

Late Life Functional Disability Index (LLFDI) (Boston University). The LLFDI is a self-reportoutcomes instrument for community-dwelling older adults. It measures change in two areas: function and disability. Items in the function component assess physical limitations related to a person's ability to do discrete activities, whereas items in the disability component assess a person's performance of expected, socially defined tasks related to IADLs. Questions in the disability component are of two types: frequency and limitation. Questions assess, for instance, "How often do you invite friends or family members into your home for a meal?" and "How limited are you in inviting friends or family into your home for a meal?" on a five point scale. Items from the disability component that measured frequency and limitation were combined into parcels (Money, Home, Health), summed, and then transformed into z-scores to minimize scaling differences between the three tests of IADL.

Observed Tasks of Daily Living (OTDL). The OTDL (Diehl, Willis, & Schaie, 1995) consists of nine tasks, with a total of 13 questions addressing three IADL domains (medication, phone usage, financial management). OTDL performance is correlated significantly with widely used measures of everyday functioning in the seven IADL domains (e.g., Fillenbaum, 1985; Lawton & Brody, 1969). Participants are observed using real-life materials (e.g., medicine bottles, and a telephone book). Each task requires participants to solve a practical problem using a printed stimulus (e.g., medicine bottle labels, and a telephone rate chart). Tasks are designed to simulate actual tasks of daily living as closely as possible, and have distinct observable elements permitting objective scoring of participants' performance. Each item is scored either yes (correct) = 1, no (incorrect) = 2, or needs cueing = 0. Participants' overall responses are scored on a scale from 0-28. The scoring of participants' performance focuses on the cognitive aspects of their problem-solving behavior. The OTDL was scored according to test directions for each participant, but adjusted so that higher scores equaled worse performance (e.g., needs cueing = 1). Items from each of the three domains were combined into parcels (Money, Home (Telephone Use), Health), summed, and then transformed into z-scores to minimize scaling differences between the three tests of IADL.

Procedure

Each participant was tested individually across two sessions on different days. Each session lasted 1.5 to 2 hours, and the second session took place within 10 days of the first. All participants were screened for health problems via telephone prior to testing, and had completed a neuropsychological testing battery within the past year in order to be included in the database (see Table 1 for participant demographics).

Testing sessions (EF or IADL) and the three tests of IADL (ILS, LLFDI, OTDL) were fully counterbalanced across participants. The nine tests of executive attention, three for each type (inhibition, task-switching, and updating) were administered in fixed order in three task sets (Task Set 1 = Stroop, N-Back, More-Less/Odd-Even; Task Set 2 = Anti-Cue, Letter-Number, Letter-Memory; Task Set 3 = Stop-Signal, Local-Global, Refreshing) which were administered in counterbalanced order across participants. Participants were given short breaks throughout testing, and one scheduled 10 minute break before either the last IADL test or the last executive attention task set. Participants were debriefed following testing, and any questions about the experiment were answered.

Chapter 5

Analyses

This experiment used a structural equation modeling (SEM) approach to examine the relationships between EF and IADL in older adults. This technique uses measured variables (indicators) to specify latent variables, e.g., the *measurement model.* This step is called confirmatory factor analysis (CFA). When the model is expanded to include the relationships between latent variables of interest, it becomes the *structural model*, thus SEM. Here, experimental tasks of executive processes that are commonly used in the cognitive psychology literature were indicators of the latent EF construct, whereas standardized tests used in the medical literature were indicators of the IADL construct.

In general, the SEM process involves five steps: model specification, model identification, model estimation, model testing, and model modification. Each is given a brief explanation here. First, theory is used to specify, or determine the variables in a model, as well as their hypothesized relationships. The type of data matrix used typically for computations in SEM programs is a variance-covariance matrix, and estimation of factor loadings and structure coefficients in SEM involves its decomposition. Mathematically, the sample variance-covariance data should be reproduced by the theoretical model. Second, if a model is properly identified it has one, unique, solution. In other words, the data might fit more than one theoretical model adequately, so constraints are imposed on the model during analysis to prevent this. In order to be identified, a model must fulfill the order condition (where the number of free parameters to be estimated is less than or equal to the number of distinct values in the model (p (p + 1) / 2 where p is the number of observed variables in the sample matrix S), and the rank condition (where there is enough information in the variance-covariance matrix to estimate all of the parameters). Third, model estimation involves using a fitting function, such as generalized least squares (GLS), to minimize the difference between the sample matrix (S) and the population covariance matrix (Σ). Fourth, in model testing, the model implied variance-covariance matrix Σ is compared to the sample variance-covariance matrix S using a Chi-square difference test. If the model does not fit, it can be modified and alternatives can be tested. The alternative approach also conducts a Chi-square difference test to determine which model the data fits best. When these models use the same data set, they are referred to as *nested* models. Three indices of fit are generally reported for each model: the Chi-square test of how well the model fits the data, the root-mean-square-error of approximation (RMSEA) which represents the difference between predicted and observed covariances, and the comparative fit index (CFI), indicating the relative improvement achieved by an alternative model (Schumacher & Lomax, 2000).

Chapter 6

Analytic Strategy

All analyses were conducted using M-Plus (Muthen & Muthen, 2007). Following standard procedures in SEM, data were screened and edited for missing values, outliers, non-linearity, and non-normality. For each model, five steps for analyzing SEM data were followed (specification, identification, estimation, testing, and modification).

The measurement models for EF and IADL were specified first, followed by the structural models between EF and IADL. Each model was identified by imposing limitations that fulfill certain necessary conditions for obtaining its unique solution. Model parameters (paths or variables) were designated as fixed (to a specific value), free (to be estimated in the model), or constrained (to be equal to other parameters). The variance of the latent variables in each of the measurement models was fixed to 1.0. Factor loadings between measured indicators and latent variables were allowed to vary freely. The order and rank conditions were met. The fitting function used to estimate the model was Maximum Likelihood (ML), recommended for use with continuous data (Schumacker & Lomax, 2004).

After the data was input, the overall omnibus fit of the model (e.g., whether or not the sample variance-covariance matrix S is similar to the population variance-covariance matrix Σ) was tested. The first criteria for fit are the non-statistical significance of the chi-square test and the RMSEA, which are global fit measures. A non-statistically significant Chi-square value indicates similarity between the sample covariance matrix (S) and the model-implied covariance matrix (*Σ*). A RMSEA value less than or equal to .05 indicates a good fit. An additional indicator of model fit, the standardized root mean square residual (SRMR) was also reported. The SRMR is the standardized difference between the observed and predicted covariance. A value of zero indicates perfect fit. This measure tends to be smaller as sample size increases and as the number of parameters in the model increases. A value less than .08 is considered a good fit.

A second criterion of model fit is the statistical significance of individual parameter estimates. The significance of the individual parameters (path estimates) was evaluated for their meaningfulness to the model (*t* values significant at the .05 level). Nested, one and two-factor alternative models of EF and IADL were then tested by constraining parameters of interest to be equal to 1.0 (e.g., a three-factor model versus a two-factor model of EF; a two-factor model versus a one-factor model of IADL). The chi-square difference test was used to evaluate the significance of the difference between nested models, and the comparative fit index (CFI) was reported to evaluate improvements in fit.

Data pre-processing for Executive Function. For the nine executive function tasks, only raw RTs and accuracy for correct trials were analyzed (see Table 2 for EF descriptive statistics). To improve interpretation, the directionality of the EF dependent measures was adjusted so that larger numbers always indicated better performance. Data screening and editing within subjects included removing RTs above and below three standard deviations from the mean for each task for each participant (< 2% of total trials). For tasks demonstrating skewness and kurtosis (Anti-cue, Local-Global, N1-back), between subjects outliers were replaced with values corresponding to either the lowest or highest end of the range (< 1% of cells) (e.g., Miyake et al., 2000; Salthouse, 2005). SEM procedures assume multivariate normality of the dependent measures (Schumacker & Lomax, 2004), and removal of outliers was completed to reduce skewness and kurtosis in order to improve the normality of the probability distribution. Finally, less than 1% of cell means were missing data.

Item parceling of Instrumental Activities of Daily Living. A parceling procedure was used to create groups of items from each test that reflected the constructs (self-report or performance-based) and domains (Money, Home, Health) of interest (see Table 3 for tests and items used in the parcels). First, items within tests were grouped according to domain (Money, Home, and Health). For example, items from the Independent Living Scales (ILS) were grouped according to whether or not they reflected questions about money, home, or health. Second, items from each of the three domains were divided into either self-report or performance-based parcels. Third, inter-item correlations were examined for each of the parcels, and items that did not correlate significantly with any other item in that parcel were excluded. Finally, the raw scores for each of the parcels were transformed into z-scores. After transformation, all of the dependent measures for EF and IADL had acceptable distributions (see Table 4 for descriptive statistics for IADL parcels). Overall, parceling served two main purposes. Importantly, parceling improved the convergent validity of the measures by creating groups of items with higher inter-item correlations, thus forming more stable self-report and performance-based IADL constructs. Other advantages of parcels are that they have more, smaller, and more equal intervals between scale points than individual items, and demonstrate higher reliability and a decreased likelihood of distributional violations (Coffman & MacCallum, 2005;

Hau & Marsh, 2001; Little et al., 2002).

Data pre-processing for Instrumental Activities of Daily Living. For the three IADL tests, data were scored according to each test's instructions and then transformed into z scores. Data was transformed because of scaling and scoring differences between the tests (see Methods), and to improve kurtosis of the dependent measures. For tests demonstrating skewness and kurtosis, between subjects outliers were replaced with values corresponding to either the lowest or highest end of the range ($< .05\%$ of cells). To improve interpretation, the directionality of the IADL dependent measures was adjusted so that larger numbers always indicated better performance.

Chapter 7

Results and Discussion

What is the underlying factor structure of executive function in older adults?

Construct validity of EF in older adults. Confirmatory factor analysis (CFA) and structural equation modeling (SEM) were used to investigate the construct validity of *EF* in older adults. This analysis addressed the separable or unitary nature of the three types of *executive attention* measured here: inhibition, task-switching, and updating. First, the measurement model for EF was tested to ensure that all of the indicators (measured variables) loaded on the predicted variables. Second, structural models were tested to examine the construct validity of EF. The factor structure of EF was specified and fit to the data by comparing a three-factor model (inhibition, task-switching, and updating) to all possible nested (one and two-factor) models (see Table 5 for fit indices).

The best-fitting model of EF is illustrated in Figure 1. The standardized factor loadings on the straight, single-headed arrows represent the covariance (strength of the relationship between the measured and latent variables in the measurement model). The correlations between the factors are represented on the curved arrows. The squared error terms represent the amount of variance that is unexplained by the latent variable (attributable to measurement error and idiosyncratic task demands).

The comparison of the full three-factor model with the nested models showed that while the three-factor model had the best fit indices, a two-factor model of Task-Switching = Updating fit the data equally well. First, the fit indices summarized for the three-factor model were all excellent. The three-factor model produced a non-significant X^2 (24, N = 75) = 27.74, p = .27, indicating that the hypothesized and real covariance data were similar. In addition, overall model fit was better compared to the alternative models (RMSEA = .05; SRMR = .05; CFI = .98). All of the factor loadings, as well as the correlations between the latent variables were significant, all *p's* < .01, and the correlations between the three latent variables (inhibition, task-switching, and updating) were moderate (.55 to .80).

A one-factor model with each of the correlations between the three latent variables fixed to 1.0 further supports the hypothesis that the executive processes of inhibition, task-switching, and updating are separable, X^2 (27, N = 75) = 44.44, p = .02. The X^2 value of the one-factor model was significant, indicating that the model not fit the sample data, and all of the fit indices were worse (RMSEA = .09; SRMR = .07; CFI = .92). In addition, the results of the chi-square difference test between the three-factor and the one-factor model were significant, X^2 (3) = 16.38, p < .01. Clearly, these executive processes measure a similar construct, yet are separable.

Three, nested two-factor models were also estimated, in which two of the three correlations among the latent variables were allowed to vary and the remaining correlation was set to 1.0. The results were as follows: Inhibition = Task-Switching, X^2 (25, N = 75) = 40.75, p = .03 (RMSEA = .08; SRMR = .06; CFI = .95); Inhibition = Updating, X^2 (25, N = 75) = 38.44, p = .05 (RMSEA = .08; SRMR = .06; CFI = .94); Task-Switching = Updating, X^2 (25, N = 75) = 30.43, p = .20 (RMSEA = .06; SRMR = .06; CFI = .97). In this set of comparisons, the two-factor model of Task-Switching = Updating also fit the data, although the fit indices were slightly worse. The result of the chi-square difference test was also non-significant, X^2 (1) = 2.69, p > .10, indicating that the two-factor model of Task-switching = Updating provides an equally good fit to the data. While one prior study of older adults suggests that a two-factor model of EF (Task Switching = Updating, and Inhibition) better describes the construct in older adults and is more parsimonious (see Hedden & Yoon, 2006), others have found that a three-factor model better describes the construct in both younger and older adults (e.g., Miyake et al., 2000; Salthouse et al., 2003). In light of the fact that the overarching goal of this study was to examine the relationships between the three executive processes and IADL, a three-factor model of EF was retained in favor of a two-factor model, since it fit the data equally well, if not slightly better. Overall, the results of the confirmatory factor analysis show that the executive processes measured here are clearly separable, yet share or tap underlying commonality. Theoretically, there is more support in the literature for a three-factor model of executive attention, although a two-factor model has been found in older adults (Hedden & Yoon, 2006), an issue which will be explored more fully in the general discussion.

What is the underlying factor structure of Instrumental Activities of Daily Living in older adults?

Construct validity of IADL in older adults. Here, a similar approach was used to test a conceptual model of IADL. First, CFA was used to test the measurement model. Item parceling was used to group similar items from each of the three tests of IADL (ILS, LLFDI, OTDL) into two types (Self-Report or Performance-Based) and three domains (Financial, Home, and Health), resulting in six parcels that were used (Performance-

Based: Money OTDL, Home ILS, and Health OTDL; Self-report: Money ILS Home ILS Health ILS) .

A two-factor model of Self-Report and Performance-Based IADL was compared to a nested, one-factor model. The best-fitting model of IADL is illustrated in Figure 2 (see Table 6 for fit indices). The two-factor model provided the best fit to the data, X^2 (8, N = 75) = 8.41, p = .39, (RMSEA = .03; SRMR = .05; CFI = .99; AIC = 1232.95), compared to the one-factor model, X^2 (9, N = 75) = 24.51, p = .004, (RMSEA = .15; SRMR = .09; CFI = .78; AIC = 1247.05). The significant X^2 value and the low CFI (.78) of the one-factor model indicate that the two-factor model is better. Each of the six indicators used loaded significantly on the latent variables, all p's < .01. The relationship between the latent variables, Self-Report and Performance-Based (.39), was significant, indicating a positive relationship between the two types of measures.

The findings of this model are congruent with others who have found a similar, positive relationship between self-report and performance-based IADLs (Barberger Gateau et al., 1992; Willis, 1996). However, this model does not lend support to the traditional conceptual framework of IADL as a construct with underlying domains (such as home management, financial management, telephone use, health, transportation), other than that the type of domain is a descriptive heuristic (e.g., the commonality shared by the test items is not driven significantly by the type of task).

What is the relationship between EF and IADL in older adults?

Relationships between EF and IADL in older adults. A structural model was specified to examine the relationships between EF and IADL in older adults. The latent executive processes (inhibition, task-switching, and updating) were modeled on the latent

IADL variables (self-report and performance-based) (see Figure 3), because these relationships were of theoretical interest. A three-factor model of EF and a two-factor model of IADL provided the best fit to the data, X^2 (7, N = 75) = 88.13, p = .23, (RMSEA = .04; SRMR = .06; CFI = .98) (see Table 7 for fit indices). As hypothesized, the strongest relationships were found between the executive attention processes and performance-based IADL. In fact, all of the relationships between the executive attention processes and self-report IADL were non-significant and close to zero (.01, .07, .10). Updating had the strongest relationship with performance-based IADL (.40, p < .01), followed by task-switching (.22, p = 12), and inhibition (.18, p = 18). While the contributions of task-switching and inhibition were non-significant, task-switching did account for (.22) of the variance in performance-based IADL, indicating that it explains some of the variance in performance-based IADL above and beyond updating.

Chapter 8

General Discussion

This dissertation used structural equation modeling to examine the relationships between three latent constructs of executive attention (inhibition, task-switching, and updating) thought to make up EF, and two latent constructs of IADL, self-report and performance-based. The first goal of this study was to examine the construct validity of EF in healthy aging older adults, and compare it to what has been found in younger adults. The second goal of the study was to examine the construct validity of IADL in healthy aging older adults. Finally, the relationships between the latent constructs of EF and IADL were examined to see what, if any, pattern exists between executive processes and IADL performance.

The results from the SEM analysis of EF confirmed the three-factor model seen in younger adults, but additionally indicated a stronger relationship between task-switching and updating in the structural model than has been seen in younger adults. The results from the SEM analysis of IADL confirmed a two-factor model of self-report versus performance-based measures. Finally, and as predicted, the structural model of the relationships between EF and IADL showed a stronger relationship between latent executive processes and performance-based IADLs. More specifically, updating in working memory was the best predictor of performance-based IADLs, although task-switching also demonstrated a relationship.

An extensive debate in the cognitive literature on EF has questioned both the convergent and discriminant validity of the executive function construct. Some findings point to executive function as a multi-faceted construct made up of executive attention processes such as inhibition, task-switching, updating in working memory, and time-sharing (Miyake et al., 2000; Salthouse, 2005). Others have debated the separability of EF from the cognitive abilities (Friedman et al., 2006; Salthouse et al., 2003). Although the main goal of this study was not to debate the construct validity of EF, few if any cognitive aging studies have examined whether the construct validity of executive function differs in older adults (although see Fisk & Sharp, 2004; Hedden & Yoon, 2006).

In terms of the first goal of this study, results from the CFA indicated that EF can be well-described as non-unitary construct, and that inhibition, task-switching, and updating function as underlying distinctive yet convergent processes. Although the correlations between the latent variables were moderate (update with inhibit (.57), update with task-switching (.83), and inhibition with task-switching (.71)), the three-factor model where the latent variables were allowed to vary freely produced a significantly better fit to the data than a one-factor model, confirming studies of younger adults using the same latent variables and similar measured indicators (e.g. Miyake et al., 2000; Friedman et al, 2006). On the other hand, a two-factor model of task-switching = updating, and inhibition, provided an equal fit to the data, and is more parsimonious. Despite strong correlations among executive attention latent variables in this study and others (.42-.63 in Miyake et al., 2000; .71-.94 in Salthouse et al., 2003; and .46-.92 in

Hedden & Yoon, 2006), models that treat EF as a single or even a dual construct tend to fit the data more poorly than do models that postulate distinct subcomponents of EF. However, there is some evidence that older adults may show “dedifferentiation”, or increased relationships among executive attention variables, in particular updating and task-switching. For instance, Hedden & Yoon (2006) found that updating and task-switching (.92) better formed one latent variable. Despite these exceptions, the results from the model reported here were interpreted in favor of a three-factor model of EF. One strength of the experimental tasks used in this study is that they are well-replicated indicators different types of executive attention. Thus, the choice to use a three-factor model of EF in this study can be made with some confidence. And finally, a point to be revisited later in the paper, is that the three executive attention latent variables contributed differentially to performance on the different types of IADL tasks.

The findings from the IADL confirmatory factor analysis are in agreement with others who have conceptualized IADL as a dual-faceted construct of self-report and performance-based tests. Traditionally, IADL has been conceptualized as a construct that is made up of domains such as managing money, using the telephone, taking medications, traveling, shopping, preparing meals, doing laundry, and housekeeping (Lawton & Brody, 1969), wherein test items are grouped accordingly into representative domains. Although the parcels from each of the tests used here were grouped according to domain (Money, Home, and Health) and type (Self-Report or Performance-Based), the items in this model had more variance in common based on the type of report than on the domain. This suggests that the way in which people report IADL, versus the type of task they are asked to perform, drives the IADL construct. This pattern might lead to the prediction that if a person has difficulty in one IADL domain, they will show performance decrements across domains. While there is limited research in this area, studies show deficits in four main IADL activities that have been correlated with global cognitive impairment, including telephone use, transportation use, taking medications, and managing finances (Barberger-Gateau et al., 1992; Bell-McGinty et al., 2002). In addition, while the two types of IADL are related (.31) in this study, there is not a clear definition of what accounts for their shared variance. However, these results are in line with a previous report (Law et al., 2001).

It was shown here that performance-based measures of IADL relate more strongly to EF than self-report measures. Although few systematic comparisons have been made of how cognition relates to the two types of IADL measures (although see Law et al., 2001), a few studies (using either the ILS or the OTDL) have found that EF is a significant predictor of performance-based IADL (Bell-McGinty et al., 2002; Owsley et al., 2002). Others have found that EF, in particular inhibition, contributes to functional status as measured by self-report measures (Jefferson e al., 2006; Royall et al., 2005). Although intuitively, clinicians report that performance-based measures appear to be more reliable indicators of IADL, this has not been demonstrated equivocally. In healthy older adults, scores on self-report and objective ratings are modestly correlated, but overestimation on self-report measures is more common (Albert et al., 2006; Willis, 1996). This finding could possibly account for the pattern of results shown in this experiment, e.g, the moderate correlation between self-report and performance-based measures, and the relationship between executive attention and performance-based, but not self-report measures. This is in contrast with studies of older adults at-risk or living in a retirement care community, that have found relationships between neuropsychological measures of EF and self-report IADL (Jefferson e al., 2006; Royall et al., 2005).

Another important finding involving the relationship between EF and IADL is that updating in working memory is significantly correlated with performance-based IADL. Age differences in task-switching and updating (in particular studies using the refreshing paradigm (Johnson et al., 2002)), are among the most well-replicated of the age-related executive attention differences. While meta-analyses of inhibition report mixed findings of greater age-related differences, age differences in updating in working memory and task-switching are found more consistently (Verhaeghen & Cerella, 2002). The findings that updating and task-switching had the strongest relationships with IADL were in-line with the study predictions, as well as the review of the cognitive psychology literature on executive attention processes.

Some study-related limitations, in particular with measuring the IADL construct, should be noted. While the particular tests (ILS, LLFDI, OTDL) have not been used before in the same study, they were chosen because they represented both self-report and performance-based items, and because they are current and recommended in the field. Although the LLFDI measures frequency and limitations of items that are represented in more traditional domains (for instance home management and financial management), this test has a different conceptual basis. Items on the LLFDI were designed to assess social participation and physical function on discrete activities, versus the traditional domain-oriented approach. This could explain the low correlations between items on this test and items on the ILS and OTDL, and why it wasn’t well-represented in the parcels. Second, these tests were designed to measure IADL in populations of older adults with higher health-related variability, and are perhaps not as sensitive to changes in the normally aging population. In addition, these tests were not timed (on purpose, as these types of tasks are often not performed under a time constraint in older, retired adults), but there are a few reports in the literature of the successful use of timed IADL tests, and their increased sensitivity to IADL impairment (Owsley et al., 2002). Third, perhaps the most obvious limitation of this study is the sample size. Texts on SEM typically recommend 100 participants at a minimum (Schumacker & Lomax, 2004). Small sample sizes have a tendency to produce non-significant Chi-square values even if the data don't fit the model, whereas large sample sizes tend to be statistically different even if they are not (but see Hau & Marsh (2001), who have reported adequate sample sizes as low as fifty based upon the model of interest). However, despite these limitations, the two-factor model of self-report and performance-based IADL provided an adequate fit to the data, and demonstrated predictable relationships with the latent executive attention variables.

In conclusion, the three-factor EF construct in older adults is similar to younger adults, although older adults demonstrated a stronger relationship between task-switching and updating. Normally aging older adults do show variability in IADL performance related to cognition, but only on performance-based IADLs. This has implications for clinical practice in term of the types of measurement tools to use. Older adults self-reports of limitations in IADL performance are unrelated to their EF, while performance-based IADL limitations are significantly related to EF. However, perfomance-based IADL limitations are not related to all types of executive attention impairments. This study found that updating in working memory, a relatively simple, lower level cognitive process, was strongly related to performance-based measures of IADL. Additionally, the relationship between task-switching and performance-based IADL was notable, although not significant here. This study shows that lower level cognitive processes have some predictive power in determining performance on IADLs, and that experimental tasks of executive attention have ecological validity in terms of studying their relationship to aging and daily life activity. While this study has implications for using and measuring executive attention processes to predict IADL performance, it also has further implications for cognitive re-training. For example, a recent study by Willis et al. (2006) showed long-term benefits of training higher-level cognitive tasks such as reasoning, on self-reported IADL status. It is likely, however, that the relationships between cognition and IADL are reciprocal in nature, and that successful interventions would address the needs of the individual at both levels.

Table 1

Demographic characteristics of older adult participants (*N* = 75)

Participant characteristics	Age	Education	MMSE	GDS	NAART
Mean (SD)	72 (6.8)	16.2 (1.8)	29 (0.8)	13.8 (.9)	46 (3.3)
Range	60-90	12-21	28-30	12-15	36-50

Note. Gender of participants was 56% female and 44% male. MMSE = Mini-Mental Status Exam; GDS = Geriatric Depression Scale; NAART = North American Adult Reading Test.

Table 2

Descriptive statistics for the dependent measures used in the confirmatory factor analysis and structural equation models of executive function ($N = 75$)

Task	Mean (SD)	Range	Skewness	Kurtosis
Inhibition				
Stroop (RT incorrect)	1.62 (.37)	0.96 to 2.79	0.73	0.53
Anti-cue (RT invalid)	0.80 (.34)	0.41 to 2.02	1.55	2.21
Stop-signal (% incorrect)	0.23 (.18)	0.00 to .79	1.13	0.67
Task-Switching				
More-less (RT invalid)	2.07 (.46)	1.32 to 3.34	0.89	0.57
Letter-number (RT invalid)	2.05 (.42)	1.16 to 3.22	0.52	0.45
Navon (RT invalid)	3.19 (.89)	1.60 to 6.22	1.07	1.11
Updating				
N 1back (% incorrect)	.02 (.03)	0.00 to 0.13	2.21	4.54
Letter-memory (% incorrect)	.22 (.11)	0.00 to 0.58	0.71	0.66
Refreshing (RT difference)	.93 (.22)	.53 to 1.54	0.55	0.08

Table 3

Number of items and tests used to create parcels for use in the confirmatory factor analysis and structural equation models of instrumental activities of daily living (*N* = 75)

Domain and Task	Self-report Items	Performance-based Items
Money ILS	10 of 11	4 of 6
Home ILS	9 of 9	4 of 5
Health ILS	19 of 19	0 of 1
Money LLFDI	0 of 2	0 of 0
Home LLFDI	6 of 6	0 of 0
Health LLFDI	6 of 6	0 of 0
Money OTDL	0 of 0	13 of 18
Home OTDL[a]	0 of 0	8 of 12
Health OTDL	0 of 0	18 of 21

Note. ILS = Independent Living Scales; LLFDI = Late-Life Functional Disability Index; OTDL = Observed Tasks of Daily Living. Of the ten parcels created, six were used in the model: three self-report (Money ILS, Home ILS, Health ILS) and three performance-based (Money OTDL, Home ILS, and Health OTDL). Summary scores for each IADL parcel for each person were transformed into z scores for analysis.

Table 4

Descriptive statistics for the dependent measures (raw scores) used in the confirmatory factor analysis and structural equation models of instrumental activities of daily living (*N* = 75)

Task	Mean (SD)	Range	Skewness	Kurtosis
Self-report				
Money ILS	18.31 (1.83)	13-20	-1.09	0.65
Home ILS	17.72 (1.41)	14-20	-0.79	-0.01
Health ILS	32.80 (2.81)	25-38	-0.57	0.18
Performance-based				
Money OTDL	12.24 (2.19)	9-19	1.02	1.37
Home ILS	7.44 (0.99)	4-9	0.24	-0.86
Health OTDL	11.36 (1.68)	9-18	1.42	3.10

Note. All dependent measures (raw scores) for IADL were transformed into z scores for analysis.

Table 5

Fit indices for the executive function full confirmatory factor analysis model and nested models (N = 75)

Model	df	X^2	RMSEA	SRMR	CFI
1. Three factor	24	27.74, p = .27	.05	.05	.98
2. One factor	27	43.12, p = .03	.09	.07	.92
3. Two factor					
a. Inhibition = Task-Switching	25	40.75, p = .03	.09	.07	.95
b. Inhibition = Updating	25	38.44, p = .05	.08	.06	.95
c. Task-Switching = Updating	25	30.43, p = .20	.05	.06	.97
4. Three factor (log corrected RTs)	24	24.54, p = .43	.02	.06	.99

Note. RMSEA = root mean square error of approximation; SMSR = standardized mean square residual; AIC = Aikake's information criteria; CFI = comparative fit index.

Table 6
Fit indices for the instrumental activities of daily living full confirmatory factor analysis model (*N* = 75)

Model	df	X^2	RMSEA	SRMR	CFI
1. Two factor (Self-Report/Performance	8	8.41, p = .39	.03	.05	.97
2. One factor	9	24.51, p = .004	.15	.09	.83

Note. RMSEA = root mean square error of approximation; SMSR = standardized mean square residual; AIC = Aikake's information criteria; CFI = comparative fit index.

Table 7
Fit indices for the full structural model of the relationship between executive function and instrumental activities of daily living (*N* = 75)

Model	df	X2	RMSEA	SRMR	CFI
1. Three-factor EF/Two-factor IADL	79	88.13, p = .23	.04	.06	.98

Note. RMSEA = root mean square error of approximation; SMSR = standardized mean square residual; AIC = Aikake's information criteria; CFI = comparative fit index.

Figure 1. Measurement Model of Executive Function.

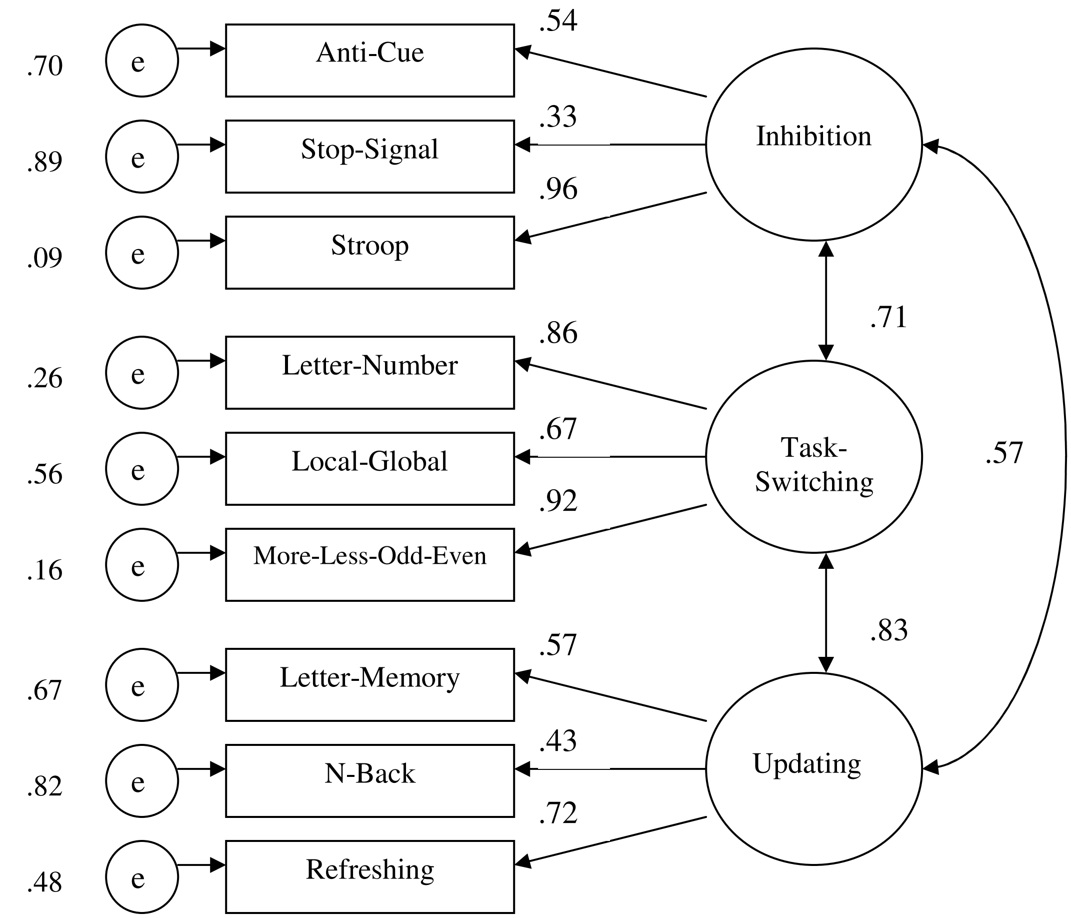


Figure 2. Measurement Model of Instrumental Activities of Daily Living

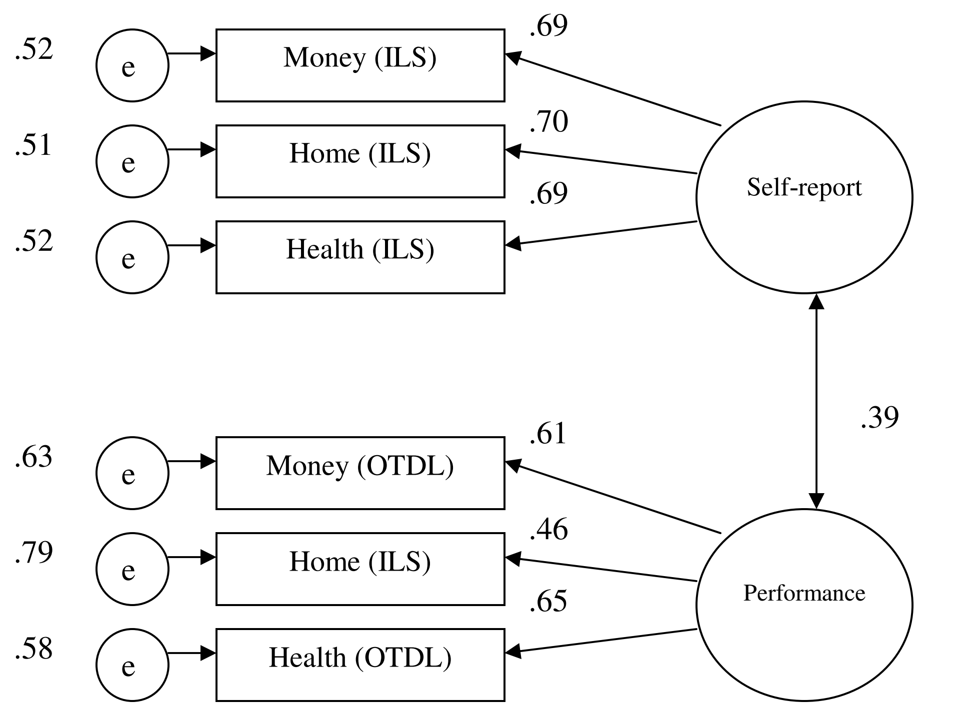
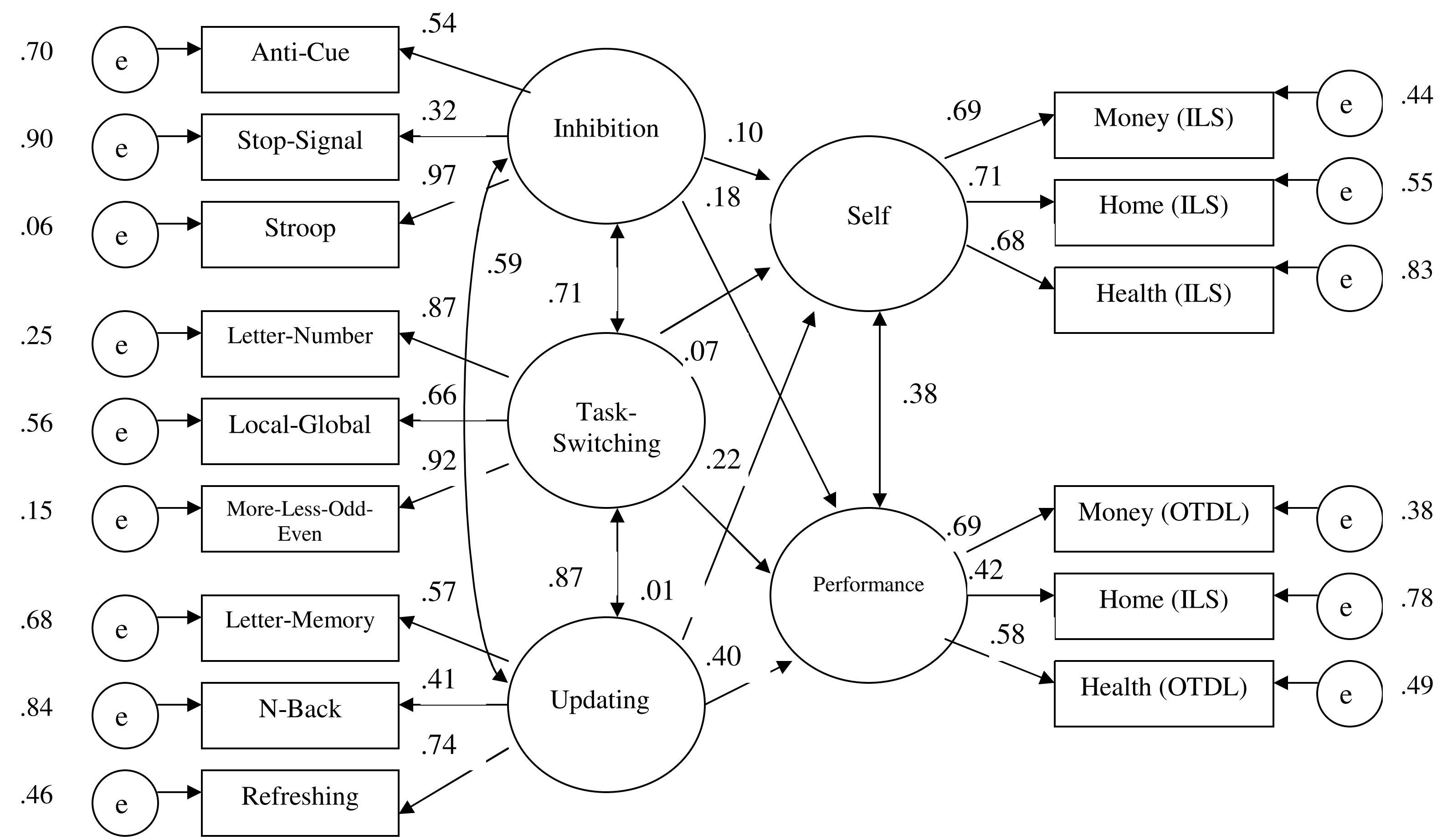


Figure 3. Structural Model of Executive Function and Instrumental Activities of Daily Living



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