EXECUTIVE FUNCTION SUBCOMPONENTS AND THEIR RELATIONS TO EVERYDAY FUNCTIONING IN HEALTHY OLDER ADULTS

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Abstract

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Everyday functioning and its executive functioning cognitive correlates were investigated in healthy older adults (HOAs) using multiple methods of functional status. We were especially interested in the contributions of both process pure and traditional measures of the executive function subcomponents of switching, inhibition, and updating. Seventy HOAs (45 young-old and 25 old-old) and 70 younger adults completed executive function and neuropsychological tests. In addition to self- and informant questionnaires of functional abilities, HOAs completed two performance-based measures. An aging effect was found on all executive function measures. Old-old older adults and their informants did not report more functional difficulties, but demonstrated more difficulties on performance-based measures relative to young-old participants. For the HOAs, after controlling for age and education, the traditional, but not process pure, executive function measures explained a significant amount of variance in the informant-report and both performance-based measures. Updating measures differentially predicted performance-based measures, while switching was a unique predictor of informant-report and problem-solving measures. These findings highlight the importance of taking a fractionated approach to the study of executive functioning and functional status, and suggest

that switching and updating abilities may contribute to age-related decline of everyday functioning in HOAs.

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Introduction

The ability to function independently in the community, including managing finances, taking medications, and preparing meals is determined by multiple social, physical, emotional, and cognitive factors. Among these, cognition has been shown to be the strongest predictor of everyday functioning within the aging population (e.g., Cahn-Weiner, Malloy, Boyle, Marran, & Salloway, 2000; Farias et al., 2009). Numerous cognitive factors have been found to contribute to functional decline in the older adult population, including global cognitive status, memory, processing speed, visuoperceputal abilities, and executive functioning. Although the extent to which particular cognitive abilities are most predictive of functional status remains unclear, executive functioning has emerged as a consistent predictor of everyday functioning in healthy older adults (HOAs).

Executive functions are broadly defined as a collection of correlated but highly separable higher order supervisory control processes involved in the flexible production and regulation of complex goal-directed problem-solving thoughts and actions, particularly in non-routine situations. Intact executive functions bolster a multitude of everyday, "real world" functions including planning and sequencing complex task goals, initiating goal-directed behavior, multitasking, sustaining attention despite interference or distraction, and terminating behavior. The frontal hypothesis of aging postulates that since the frontal areas disproportionately deteriorate earlier and more severely than other cerebral areas with age, the cognitive functions dependent on the integrity of the prefrontal regions will be among the first to deteriorate (e.g., Daigneault, Braun, & Whitaker, 1992; Dempster, 1992; West, 1996). Given that "complex daily tasks have the hallmark components of executive function" (Willis et al., 1998, p. 570), it is clear that the well-established age-related declines in executive functioning could have negative consequences on functional outcomes.

Although executive functioning as a neuropsychological construct has long been considered a unitary, general purpose higher order ability, often measured with a single, complex "frontal lobe task" (e.g., WCST; Friedman et al., 2008), it may be more accurately characterized as a collection of multiple related but separable or dissociable executive processes, a pattern referred to as the "unity and diversity" of executive functions (Teuber, 1972). This multicomponent or "fractionated" view implies that different executive subcomponents are partially independent, with low correlations (diversity), yet sufficiently related to represent a unique executive functioning construct (unity) (Friedman, Miyake, Robinson, & Hewitt, 2011).

There have been many proposed models that have explored the underlying dimensions of various batteries of supposed executive functioning tasks to determine the existence of differentiated components, with several being identified (see also Packwood, Hodgetts, & Tremblay, 2011). For example, Miyake et al.'s (2000) influential model used latent variable analysis in a sample of younger adults using nine experimental executive tasks to specify the extent of the relationship among three commonly identified subcomponents of executive functioning: task shifting, inhibition, and updating. Task shifting, also referred to as "attention switching" or "task switching," involves flexibly switching attention and cognitive control back and forth between multiple relevant tasks or subtasks, operations, or mental sets while overcoming proactive interference or negative priming due to having previously performed a different operation on the same type of stimuli (Miyake et al., 2000; Monsell, 2003). Inhibition concerns the ability to deliberately suppress and override dominant, automatic, or prepotent conflicting responses while ignoring extraneous information. Lastly, the updating component refers to monitoring and evaluating incoming information for task-relevance and then appropriately revising the existing contents in working memory by modifying older, no longer relevant information with more recent and relevant information (Miyake et al., 2000; Morris & Jones, 1990).

Results from Miyake et al.'s study provided support for the non-unitary, multifaceted nature of executive functioning. These authors found that the three subcomponents were moderately correlated, but clearly distinguishable, and differentially contributed to performance on various complex executive functioning tasks (e.g., WCST). More recent studies, including neuroimaging studies (e.g., Collette & Van der Linden, 2002), have also found separable executive components, most frequently a three-factor model with similar components as Miyake et al. (2000), with other populations including older adults, children, and clinical populations (e.g., Androver-Roig, Sesé, Barceló, & Palmer, 2012; de Frias, Dixon, & Strauss, 2009; Hedden & Yoon, 2006; Hull, Martin, Beier, Lane, & Hamilton, 2008; Novakovic-Agopian et al., 2014; Vaughan & Giovanello, 2010). Although other executive functions have been examined, including dual tasking, planning, and access to long-term memory (Fisk & Sharp, 2004; Ginani et al., 2011), task switching, inhibition, and updating have most frequently been identified as important subprocesses in the executive function research. However, caution is needed when choosing the tasks to assess these three subcomponents as traditional neuropsychological tests may not be as ideal for isolating individual executive subcomponents as experimental tasks "matched as far as possible in terms of lower-level processes" (Dafters, 2006, p. 181).

Previous studies have shown a clear relationship between executive functioning and functional abilities (e.g., McAlister & Schmitter-Edgecombe, 2013; Schmitter-Edgecombe & Parsey, 2014). However, most studies have not taken a "fractionated" approach to studying the relationship between executive functions and functional abilities, and instead, have relied on more broad conceptualizations and generally assessed only one component of executive functioning. Therefore, the specific executive functioning subcomponents most involved in functional abilities remains unclear.

Studies that have used traditional neuropsychological measures to investigate the relationship between functional abilities and subcomponents of executive functioning have yielded mixed results. For example, with cognitively healthy older adults, Jefferson, Paul, Ozonoff, and Cohen (2006) found that inhibition (as measured by DKEFS Color-Word Interference Test) was most strongly related to IADL impairment, while Bell-McGinty and colleagues (Bell-McKinty, Podell, Franzen, Baird, & Williams, 2002) identified task-switching (as measured by Trail Making Test-Part B), and Lewis and Miller (2007) planning (as measured by Tower of London and Porteus Maze Test), as most predictive. These varying conclusions may be resultant of the different executive functioning measures that were used and the fact that these measures are not “process pure” in that they may also be heavily reliant on other cognitive processes (e.g., speeded processing). Studies have also found that the relationship between executive functioning and functional status may vary depending on whether performance- or questionnaire-based assessments are utilized (Gold, 2012). For example, Cahn-Weiner, Boyle, and Malloy (2002) found that task switching significantly correlated with both performance-based (i.e., behavior simulation) and informant-rated measures of IADLs, while verbal fluency performance was strongly associated with informant-report only. These findings suggest that executive subprocesses may be differentially related to IADLs depending on assessment measure.

Several recent studies have utilized more “process pure” measures of executive function subcomponents to explore the relationship between executive functions and IADLs. For example, Vaughan and Giovanello (2010) used computerized experimental measures of task-switching, inhibition, and updating to explore the relationship between executive subprocesses and functional abilities in cognitively healthy older adults. They showed that task switching had a strong and significant relationship with performance-based (i.e., behavior simulation), but not self-report, IADLs. Also using computerized experimental measures of executive subcomponents from Miyake et al.’s (2000) model with community-dwelling older adults, Han (2010) found that a composite measure of inhibition was the best predictor of a performance-based measure (i.e., behavior simulation) of IADLs.

To our knowledge, few studies have examined the relationship between executive function subprocesses and multiple measures of functional ability in healthy older adults, and none have included informant-report. The primary aim of this study was to identify which executive function subcomponents, as measured by both “process pure” and traditional neuropsychological measures, were most related to everyday activity completion in healthy older adults across several methods for assessing functional status (i.e., self- and informant-report, behavior simulation and everyday problem solving). More specifically, we sought to evaluate whether the executive function subcomponents identified as important in Miyake et al.’s (2000) influential model (i.e., task switching, inhibition, and updating) would account for significant variance in functional status. In addition, despite suggestions that older adults aged 75+ are at greater risk for limitation in functional status (Lafortune & Balestat, 2007), there is limited understanding of the course of change in functional abilities with advanced age. Therefore, we were interested in comparing young-old (age 60-74) and old-old (age 75+) older adult groups’ performances on the multiple measures of functional abilities as well as executive functioning. We expected that the old-old would perform more poorly than the young-old older adults who would perform more poorly than the younger adults on measures of functional as well as on both process pure and traditional neuropsychological tests of executive functioning. Based on prior literature (e.g., Han, 2010; Vaughan & Giovanello, 2010), difficulties with task switching and inhibition were hypothesized to uniquely account for difficulties associated with everyday activity completion as measured by both questionnaire and the behavioral simulation measure. With few studies having explored the role of updating in functional abilities, we were interested in the unique contribution of updating and hypothesized that it would account for significant variance in everyday functioning documented by questionnaires. Given the demands of the performance-based measures, we also expected that the ability to update information would uniquely account for difficulties on the behavioral simulation and everyday problem solving measures.

Method

Participants

Participants were 70 community-dwelling, cognitively healthy older adults (HOAs), aged 50 and above, and 70 undergraduate students (younger adults, YAs) (Table 1). To assess whether functional and executive function difficulties were more common in individuals age 75+ rather than also being apparent in the young-old, we also differentiated the HOAs into two age groups, young-old (N = 44; M = 67.84, SD = 3.68; range 61-74; 32F, 12M) and old-old (N = 25; M = 78.84, SD = 3.33; range 75-87, 13F, 12M).

Older adult participants were recruited through advertisements, community health and wellness fairs, physician and local agency referrals, and from past studies in our laboratory.

Younger adult participants were recruited through the Washington State University psychology participant pool and received course credit. Initial screening for older adult participants was conducted over the phone and included: (a) a medical interview to rule out exclusion criteria, and (b) the Telephone Interview for Cognitive Status (TICS) to exclude participants who scored below 27 (equivalent of an MMSE of 24) on a measure of global cognitive functioning (Brandt & Folstein, 2003). Exclusionary criteria included history of brain surgery, cerebrovascular accident, or head trauma with permanent brain lesion; current or recent (i.e., within the past year) psychoactive substance abuse; a known medical, neurological, or psychiatric cause of cognitive dysfunction; and self- or knowledgeable informant-report of significant memory complaints or changes in cognitive or functional ability.

Participants meeting initial screening criteria completed laboratory-based standardized and experimental neuropsychological tests across two testing sessions. The first session lasted approximately 3 hours and the second session 2 hours. As compensation, older adult participants were given pre-paid parking passes, travel compensation, a report documenting their performance on the neuropsychological tests, and $20 for completing the second session. Older adult participants did not meet criteria for dementia (American Psychiatric Association, 2000) or Mild Cognitive Impairment (MCI) as outline by the National Institute on Aging-Alzheimer's Association workgroup (Albert et al., 2011).

Measures

Executive function measures. The executive function measures represent three commonly identified subcomponents of executive functioning: shifting, inhibition, and updating. Both a "process pure" measure and a traditional neuropsychological measure were chosen for each subcomponent.

Shifting.

Number-Letter Task (Miyake et al., 2000; Rogers & Monsell, 1995). A number-letter pair (e.g., 7G) was presented in one of four quadrants of a square on a computer screen. Participants were asked to indicate as quickly and accurately as possible with a button press whether the number was odd or even (2, 4, 6, and 8 for even; 3, 5, 7, and 9 for odd) when the number-letter pair was presented in either of the top two quadrants and whether the letter is a consonant or vowel (G, K, M, and R for consonant; A, E, I and U for vowel) when the number-letter pair was presented in either of the bottom two quadrants. Number-letter pairs were presented only in the top two quadrants in the first block of 32 trials, only in the bottom two quadrants in the second block of 32 trials, and randomly in all four quadrants in a clockwise rotation in the third block of 128 trials. There were 10 practice items in the first two blocks and 24 in the third block. Trials in the first two blocks did not require switching, whereas half of the trials in the third block required switching between two types of categorization operations at predictable positions. Stimuli were presented until a response was made with a 150 ms inter-trial interval. Shift cost was the difference between the average reaction times of trials in the third block that required a mental shift (trials from the upper left and lower right quadrants) and the average reaction times of trials from the first two blocks in which no shift was necessary, divided by the average reaction time of trials in the first half.

Trail Making Test (Reitan & Wolfson, 1985). Participants were asked to rapidly alternate between connecting numbers (Trails A), and numbers and letters (Trails B). The time the individual took to complete Trails B minus Trails A was used as a measure of shifting (e.g., Vazzana et al., 2010).

Inhibition.

Antisaccade task (Miyake et al., 2000; Roberts, Hager, & Heron, 1994). In each trial, a fixation point was presented in the center of the screen for a variable duration (one of nine times randomly between 1500 and 3500 ms in 250 ms intervals). A visual cue (a 1/8-in. black square) was displayed for 225 ms on either the left or right side of the screen followed by a target stimulus (7/16-in. arrow inside an open square) for 175 ms on the opposite side of the screen before it was masked by gray cross-hatching. The mask remained on the screen until the participant indicated the direction of the arrow (left, up, or right) with a button press response. Cues and targets were presented 3.4-in. from the fixation point. Since the targets appeared only briefly, participants were required to inhibit the reflexive response of looking at the cues as this would make it more difficult to correctly identify the direction of the arrow. After 22 practice trials, participants completed three blocks of 30 trials for a total of 90 trials. The number of trials answered correctly served as the dependent measure.

Hayling Sentence Completion test (Burgess & Shallice, 1997). Participants were read two sets of 15 sentences in which the final word was missing. In the first half, participants were asked to complete the sentences with a word related to the sentence as quickly as possible, while in the second half, participants were asked to complete the sentences with a word unrelated to the sentence as quickly as possible. The total time to complete sentences in the second half minus the total time to complete sentences in the first half was used as a measure of inhibition.

Updating.

Keep Track Task (Miyake et al., 2000; Yntema, 1963). In each trial, participants were first shown target categories at the bottom of a computer screen. Target categories remained on the screen while fifteen words, two or three exemplars from each of six categories (animals, colors, sports, furniture, instruments, fruits), were presented serially and in random order for

2000ms apiece. Participants were asked to recall the last word presented in each of the target categories while the examiner wrote down their responses and encouraged them to guess if an insufficient number of words were recalled. Thus, participants had to closely monitor the words presented and update their working memory representations for the appropriate categories when the presented word was a member of the target categories. All six categories and exemplars were presented to participants before the task to ensure they knew to which category each word belonged. They practiced on a sample and two practice trials with two target categories. Participants then performed three trials for each of two, three, and four categories, recalling a total of 27 words. The number of words correctly recalled was used as a measure of updating.

Reading Span task (Daneman & Carpenter, 1980). Participants were presented with 60 sentences, ranging from 14 to 22 words in length, on a 5.5 x 8.5-in. white cardstock booklet, one at a time, and asked to read each sentence out loud. Immediately after a sentence was read, the card was turned, and participants were asked to read the next sentence. Following the last sentence in a set, a card signaled participants to recall the last word of each sentence of the set in the order in which they occurred. The task was discontinued if participants failed to recall the last word of each sentence in all three sets of a particular block, regardless of if they were in the correct order. Participants first practiced on a two-sentence set. Following this, the test blocks began with three two-sentence sets and progressed to a maximum of three six-sentence sets. The total number of words correctly recalled was used as a measure of updating.

Neuropsychological measures.

The following measures represent the cognitive constructs of memory, language, and visuospatial abilities. They were chosen as constructs not expected to have as significant a relationship with functional abilities in healthy older adults.

Memory Assessment Scale: Prose Memory subtest (MAS; Williams, 1991). After hearing a three-sentence story, participants were asked nine questions about the story, both immediately and after a long delay. Retrospective memory was represented by the total number of correctly answered questions at the long delay.

Facial Recognition Test (Benton, Sivan, Hamsher, Varney, & Spreen, 1994). Participants were asked to select faces from black and white photgraphs that matched the original target face. Total number correct was used as a measure of visuospatial abilities.

Boston Naming Test (BNT; Ivnik, Malec, Smith, Tangalos, & Petersen, 1996). Participants were asked to name line-drawing of objects. The BNT was administered and scored using the standardized procedures outlined by Kaplan et al. (1983). Total naming score was used as a measure of language abilities.

Functional status measures.

Instrumental Activities of Daily Living: Compensation Scale (IADL-C; Schmitter-Edgecombe, Parsey, & Lamb, 2014). Participants and their knowledgeable informants completed the IADL-C, a 27-item questionnaire of everyday functioning. Each item was rated using an 8-point Likert scale, ranging from 1 (*independent, as well as ever, no aid*) to 8 (*not able to complete activity anymore*). Ratings included four levels of independent functioning and three levels of needing increasing amounts of assistance. Categories for indicating that the participant "*does not need to complete the activity*" or that there is "*no basis for judgment*" (informant version only) were also presented. A log-transformed total score was created by summing the items with higher scores indicating poorer functional abilities.

UCSD Performance-Based Skills Assessment-Brief Version (UPSA-Brief; Mausbach, B. T., Harvey, P. D., Goldman, S. R., Jeste, D. V., & Patterson, T. L., 20007; Patterson, T.L., Goldman, S., McKibbin, C. L., Hughs, T., & Jeste, D. V., 2001). Participants were asked to role-play tasks in two areas of functioning: communication (e.g., reschedule an appointment) and finances (e.g., write a check). The percentage of items correct on each subscale was multiplied by a weight of 50, and the two subscale scores were summed for a total score.

The Everyday Problems Test (EPT, Willis & Marsiske, 1993). Participants were presented with 14 everyday stimuli (e.g., medication labels, transportation schedules), representing seven IADL domains (medications, telephone, transportation, household, finance, shopping, and meal preparation) and asked to answer two paper and pencil, open-ended questions about each stimulus. The total number of correct items out of 28 was used as the dependent measure.

Results

Analyses

t-tests and one-way ANOVAs were used to compare group performances (i.e., younger adults, young-old and old-old older adults) on demographic variables, everyday functioning and neuropsychological measures, and both traditional and “process pure” measures of executive functioning. When group differences were found, Tukey’s HSD post hoc comparisons were used. Pearson correlations examined for relationships between process pure and traditional neuropsychological measures of the same executive functioning subcomponent. Pearson correlations were also used to compare executive function and neuropsychological variables to everyday functioning measures. Measures (i.e., IADL-C) not normally distributed were log-transformed. Hierarchical regression analyses were used to examine the relationship between both process pure and traditional measures of executive functioning subcomponent predictors (i.e., task shifting, inhibition, and updating) and functional status performances across all functional status measures for older adults. Young-old and old-old older adult groups were combined for the regression analyses. Younger adults were excluded from regression analyses as younger adults were not the primary focus of this study. Age and education were both entered into the first block of the regression. The three executive function subcomponents were then entered simultaneously in the next block to determine if they held any unique and predictive value for each of the functional status measures. Hierarchical regression analyses were also used to examine the relationship between neuropsychological measures (i.e., memory, language, and visuospatial abilities), and functional status performances.

Participant Characteristics

Table 1 shows the demographic data for the younger and older adult groups. Mean education was similar for the older adult groups (p = .98) and higher than the younger adults (p's < .02). There was no significant difference in the gender distribution of the groups, $\chi^2(2) = 3.56$, $p = .17$.

Executive Function and Neuropsychological Predictors

Table 2 shows the means and standard deviations for the executive function and neuropsychological variables for the older and younger adult groups.

Process pure executive function measures.

One-way ANOVAs revealed significant differences between groups on all of the process pure executive function measures, *F*s > 12.77, *p*s < .001. Tukey post hoc comparisons revealed that the older adults performed more poorly than the younger adults on all measures, p's < .01, and that the old-old older adults performed more poorly than the young-old older adults on measures of inhibition (p < .001) and updating (p < .001) but not switching (p = .53).

Traditional executive function measures.

One-way ANOVAs revealed significant differences between groups on all of the traditional executive function measures, *F*s > 13.69, *p*s < .001. Tukey post hoc comparisons revealed that the older adults performed more poorly than the younger adults on the inhibition (*p*'s < .001) and updating measures (*p*'s < .05). The old-old older adult group performed similarly to the young-old older adult group on the measure of inhibition (*p* = .48) but not updating (*p* < .01). Both the younger adults and young-old older adults performed similarly on a measure of switching (*p* = .25), and better than the old-old older adults (*p*'s < .01).

Neuropsychological measures.

One-way ANOVAs revealed significant differences between groups in measures of memory, *F* = 5.46, and language, *F* = 16.98, but not visuospatial abilities, *F* = .33. Consistent with the aging literature (Schmitter-Edgecombe, Vesneski, & Jones, 2000), in comparison to the younger adults, the older adults performed better on a measure of language (*p*'s < .001), and the performance of the young-old and old-old adults did not differ (*p* = .31). Both younger adults and young-old adults (*p* = .11), and younger and old-old (*p* = .87) performed similarly on a memory measure (*p* = .11), but young-old performed better than old-old adults (*p* < .01).

Everyday Functioning Measures

Summary data for the everyday functioning measures is found in Table 3. Younger adults were not administered the everyday functioning measures, therefore no age comparisons could be made. For the young-old and old-old older adult groups, no significant differences were noted for the IADL-C for either self-report, *t*(61) = -.46, *p* = .65, or informant report, *t*(50) = -.34, *p* = .74. However, there were significant differences between the age groups on both performance-based measures [EPT, *t*(65) = 3.35, *p* < .01; UPSA , *t*(67) = 2.59, *p* < .05] with the old-old older adult group performing more poorly than the young-old older adult group.

Intercorrelations between Executive Function and Neuropsychological Measures

Table 4 shows the intercorrelations amongst the executive functioning and neuropsychological measures for the HOAs. A more conservative significance value of $p < .01$ was used due to the large number of comparisons being made. There were no significant correlations amongst the three process pure measures of executive functioning (*rs* between -.30 and .27), suggesting relatively independent dissociable aspects of executive functioning. In contrast, there were significant correlations among the three traditional measures of executive function (see Table 4), suggesting some overlap in abilities being measured. Furthermore, the traditional measure of switching (i.e., Trails B) significantly correlated with the process pure measures of inhibition (i.e., Antisaccade; $r = -.36$) and updating (i.e., Keep Track Task; $r = -.43$) but not with the process pure measure of switching (i.e., Number Letter Task; $r = .23$, $p = .06$). In addition, while the traditional and process pure measures of inhibition did not significantly correlate ($r = -.15$, $p = .22$), there were significant correlations between the updating measures ($r = .53$, $p < .001$). Only one executive function measure (i.e., Reading Span) significantly correlated with the neuropsychological measures of memory ($r = .36$) and language ($r = .43$), suggesting relatively independent cognitive domain constructs.

Intercorrelations between Measures of Everyday Functioning

Table 5 shows the intercorrelations amongst the four measures of functional status for the entire HOA group. The self- and informant-report IADL-C did not correlate with each other. No significant correlations were found between both the self- or informant-report IADL-C and the two performance-based measures (i.e., EPT and UPSA). The two performance-based measures were significantly correlated, $r = .50$, $p < .001$.

Regression Analyses

Hierarchical regression analyses were conducted to investigate whether the process pure, traditional, or neuropsychological measures could predict everyday functioning for the HOAs. Total scores for the self- and informant-report IADL-C, UPSA, and EPT were used as the primary outcome measures of everyday functioning. Demographics (i.e., age and education) were entered in the first block, and then the three process pure measures of executive functioning were entered simultaneously into the second block to determine if they held any unique and predictive value. This method was repeated with the traditional executive function and neuropsychological measures. The Variance Inflation Factors for each variable were less than 2.04 indicating little multicollinearity within the three sets of predictor variables. Table 6 shows correlations amongst the predictor and criterion variables. Table 7 displays the beta coefficients for all of the predictors entered into the regression analyses.

Process pure executive function measures.

Analysis of the regression models (see Table 7) revealed that the process pure executive function measures did not account for significant variance above and beyond age and education for either the self-report IADL-C [$\Delta F(3, 53) = 1.16$, $p = .33$], informant-report IADL-C [$\Delta F(3, 41) = .22$, $p = .88$], EPT [$\Delta F(3, 57) = 1.61$, $p = .20$], or UPSA [$\Delta F(3, 59) = 2.14$, $p = .11$]. While the Number Letter Task (switching) approached significance as an important predictor for the UPSA ($t = -1.79$, $p = .08$), age ($t = -2.26$, $p < .05$), education ($t = 3.61$, $p < .01$), and the Keep Track Task (updating) ($t = 2.16$, $p < .05$) each contributed a significant amount of the variance for the EPT after controlling for the other variables.

Traditional executive function measures.

The traditional executive function measures did not account for significant variance above and beyond age and education for the self-report IADL-C [$\Delta F(3, 54) = .01$, $p = 1.00$]. In contrast, the traditional executive function measures accounted for significant variance, above and beyond variance explained by age and education, for the informant-report IADL-C [$\Delta F(3, 43) = 4.07$, $p < .05$], UPSA [$\Delta F(3, 61) = 7.06$, $p < .001$], and EPT [$\Delta F(3, 59) = 7.91$, $p < .001$]. Trails B (switching) emerged as an important predictor for the informant-report IADL-C ($t = 3.27$, $p < .01$), and education ($t = 2.50$, $p < .05$) and Trails B ($t = -3.83$, $p < .001$) both contributed a significant amount of the variability for the EPT after controlling for the other variables. For the UPSA, Reading Span (updating) contributed a significant amount of the variability after controlling for the other variables ($t = 3.31$, $p < .01$), although Trails B approached significance ($t = -1.99$, $p = .05$).

Neuropsychological measures.

The neuropsychological measures did not account for significant variance above and beyond age for the self-report IADL-C [$\Delta F(3, 56) = .65$, $p = .58$], informant-report IADL-C [$\Delta F(3, 46) = .24$, $p = .87$], or UPSA [$\Delta F(3, 63) = 1.63$, $p = .19$]. Education contributed a significant amount of the variability for the self-report IADL-C after controlling for the other variables ($t = -2.08$, $p < .05$). For the EPT, the neuropsychological measures accounted for significant variance, above and beyond the variance explained by age and education [$\Delta F(3, 61) = 3.27$, $p < .05$], however, age ($t = -2.22$, $p < .05$) and education ($t = 3.78$, $p < .001$) were the only predictors to contribute a significant amount of the variability after controlling for the other variables. There were no significant neuropsychological predictors for any of the everyday functioning measures.

Discussion

In this study, we examined the influence of executive function subcomponents (i.e., task switching, inhibition, and updating) on everyday functioning in healthy aging. We found that both process pure and traditional executive function measures assessing subcomponents of executive functioning showed sensitivity to the healthy aging process. More specifically, older adults performed more poorly than younger adults on all but one measure (Trails B). The old-old older adults performed more poorly than the young-old on both the traditional and process-pure measure of updating, which is consistent with findings of Sorel and Pennequin (2008). Furthermore, a measure of inhibition (Hayling) and of switching (Number Letter Task) also differentiated between the older adult groups. In contrast, there were fewer age differences on cognitive measures assessing other domains of cognitive functioning. Although this may have been due to the cognitive domains, it may also be a function of the sensitivity of the tasks used to measures these domains. These results are consistent with the aging literature suggesting that subclinical executive deficits exist with advanced age and may have implications for everyday functioning (e.g., Albert, Moss, Tanzi, & Jones, 2001; Ready, Ott, Grace, & Cahn-Weiner, 2003).

On the proxy measures of everyday functioning, neither the old-old participants nor their informants reported significantly more functional problems on the IADL-C compared to the young-old older adults. This contrasts with a recent study that used the same instrument with a larger sample size and found that old-old adults were reported by their informants to have more cognitive difficulties than young-old adults (Schmitter-Edgecombe, Parsey, & Lamb, 2014). However, many of the HOAs in this study endorsed full independence on the measure or the ceiling effect, limiting the variance and sensitivity of this measure with this cognitively healthy sample. The performance-based measures, however, showed sensitivity to the healthy aging process. The old-old older adult group performed significantly poorer than the young-old group on both administered performance-based measures (i.e., UPSA, EPT). These findings are consistent with previous studies (e.g., Lafortune & Balestat, 2007; Schmitter-Edgecombe, Parsey, & Cook, 2011) in suggesting that individuals aged 75 and above are at greater risk for difficulties with everyday functioning.

These findings may also suggest that subtle functional difficulties in cognitively healthy old-old older adults may be better captured with performance-based measures compared to either self- or informant-report questionnaires. However, there is currently no agreed-upon or best proxy for everyday functioning as both performance-based measures and questionnaires have their strengths and weaknesses. For example, performance-based measures assess functional capacity directly by having an individual enact a task with formal evaluation of performances in a controlled artificial laboratory setting. Therefore, difficulties on performance-based measures do not necessarily translate into meaningful difficulties in the everyday environment where an individual might use compensatory aids or apply a different strategy to complete a task (e.g., automatic bill pay as opposed to writing out a check). In contrast, questionnaires are representations of performances across multiple unstructured environments and activities over extended periods of time, but they are also subject to reporter biases and may not be sensitive to functional changes that occur early in the healthy aging process.

It has previously been suggested that questionnaires and performance-based measures of everyday functioning may assess different aspects of functional abilities (Schmitter-Edgecombe et al., 2011), indicating that both may provide important information about everyday functioning. While questionnaires may tap into knowledge gained through multiple experiences completing everyday tasks, everyday problem solving measures, for example, may tap into the ability to use and apply everyday problems (Schmitter-Edgecombe et al., 2011. Consistent with this idea and with other prior studies with HOAs (e.g., Kempen, Steverink, Ormel, & Deeg, 1996; Reuben, Valle, Hays, & Siu, 1995), we found that neither the self- nor informant-report questionnaires correlated with either of the performance-based measures. While questionnaires and performance-based measures have been widely used as proxy measures of functional status in prior research, it has also been argued that direct observation of individuals within an everyday environment may provide a more valid determination of functional status (Marcotte et al., 2010). One study found that, although a self-report questionnaire and problem-solving measure did not correlate with each other, both functional status measures but not cognitive variables were unique predictors of a direct observation measure (Schmitter-Edgecombe et al., 2011). The authors suggested that, at least in the cognitively healthy population, the proxy functional measures of self-report and problem-solving measures may provide better information regarding the quality of everyday activity completion than neuropsychological test data.

We also found that the two performance-based measures significantly correlated with each other. That is, despite representing different ways of measuring functional abilities, older adults who performed more poorly on the behavioral simulation measure (UPSA) also showed poorer everyday problem-solving abilities (EPT). In contrast, the self-report of functional abilities was not significantly correlated with informant-report. While self-report measures have shown poor relations with objective measures of cognition and poor reliability in individuals with deficits in self-awareness, they are generally accurate indicators of everyday functioning for cognitively HOAs who demonstrate insight into their functional abilities (e.g., Alexander et al., 2000; Farias, Mungas, & Jagust, 2005). However, with many similar findings of a weak correlations between self- and informant-reports in the literature (e.g., Farias et al., 2005), there also remains debate regarding the use of self- or informant-report in HOAs.

In addition to examining the relationships between process pure and traditional executive measures and how they related to everyday functioning, we were interested in whether the relationship between executive subcomponents might differ as a result of the functional status measure used to assess everyday functioning. We found no significant correlations among the process pure measures. These findings suggest relatively independent and dissociable aspects of executive functioning, and are similar to other multifactorial models of executive functioning (e.g., Fisk & Sharp, 2004; Friedman et al., 2008; Hull, Martin, Beier, Lane, & Hamilton, 2008; Miyake, 2000; Vaughan & Giovanello, 2010). Thus, when measured with tasks that are less likely to significantly rely on additional cognitive abilities, circumscribed executive function subcomponents emerged. In contrast, all three traditional executive measures were significantly correlated suggesting overlap in the abilities being measured. Similarly, when examining relationships between process pure and traditional measures of the same executive function subcomponent, we found that, although the updating measures correlated, neither the switching nor the inhibition measures were significantly correlated. The low correlations between the two switching and two inhibition measures may suggest that the process pure and traditional measures are not measuring the same constructs. This further reflects the task impurity problems associated with executive functioning measures and that traditional measures may not be as ideal for isolating individual executive processes as experimental tasks. Moreover, only one executive function measure (i.e., Reading Span) significantly correlated with neuropsychological measures assessing other domains of cognitive function (memory, language, visuospatial abilities) suggesting relatively independent measurement of executive function abilities in comparison to other cognitive domains.

Results from the regression analyses revealed that, consistent with our hypotheses, switching (i.e., Trails B) explained a significant amount of the variability for informant-report and problem-solving measures after controlling for the other predictors, while also approaching significance for the behavior simulation measure. Our findings are consistent with prior research showing switching abilities are important for functional abilities in HOAs (e.g., Bell-McGinty et al., 2002) and individuals with cognitive impairment (e.g., McAlister, Schmitter-Edgecombe, & Lamb, submitted; Yeh et al., 2011). Moreover, in contrast with several other studies of HOAs (i.e., Jefferson et al, 2006; Han, 2010), the results from the regression analyses did not show inhibition abilities to be strong predictors of everyday functioning despite both of our inhibition tasks likely measuring different aspects of inhibition. Regression analyses further revealed that updating explained a significant amount of the variability for both of the performance-based measures (UPSA and EPT) after controlling for the other predictors, although the updating measures differed across them. Although we hypothesized that updating would also be important for the questionnaire measures, this was not found but may have been due to the limited variance within the questionnaires for the cognitively HOAs. Despite its importance, relatively few studies have examined updating abilities independent of working memory conceptualizations or considered its relationship with everyday functioning, and further research appears warranted. Consistent with prior research (e.g., Schmitter-Edgecombe et al., 2011), results from the regression analyses using the neuropsychological measures of memory, language, and visuospatial abilities found that, despite accounting for significant variance in the EPT, none of the measures explained a significant amount of the variability after controlling for the other predictors.

For the regression analyses, we found that executive subprocesses are differentially related to IADLs depending on assessment measure. While informant-report was associated with switching, performance-based measures were related to both switching and updating abilities consistent with the findings of Cahn-Weiner et al. (2002). Similar to Vaughan and Giovanello (2010), none of the executive subcomponents were associated with self-report of everyday functioning. Moreover, on average, both the neuropsychological and executive function predictors qualitatively accounted for more variance in the performance-based measures than the questionnaires although this may have been related to the limited variability for HOAs in the questionnaire measure. This suggests that performances on the performance-based measures may be more closely tied with executive function correlates than questionnaires, and self-report questionnaires in particular. Similarly, while no specific neuropsychological measures accounted for a significant amount of the variability after controlling for the other variables, the neuropsychological measures accounted for a significant change in variance for the problem-solving measure. This suggests that the problem-solving measure, compared to other functional measures, may be more closely related with a variety of cognitive abilities, in addition to the executive subprocesses of updating and switching.

Findings from the regression analyses also showed that, while there was no significant change in the variance accounted for when the process pure measures were added into the models, there was a significant change across all functional measures except for self-report when the traditional measures were added. Furthermore, on average, the traditional measures of executive functioning qualitatively accounted for more of the variance in functional status across multiple measures relative to process pure measures. This may suggest that traditional executive measures are likely capturing additional cognitive abilities (e.g., processing speed) as well as lower-level within domain abilities. For example, in addition to Trails B being related to switching, processing speed, and visuomotor abilities, our findings showed that it also correlated with measures of inhibition and updating. However, despite traditional measures not being as ideal for isolating individual executive subprocesses as perhaps more experimental and process pure measures, our findings suggest that they may be better for predicting functional abilities.

Although the variance accounted for in functional status by cognition in this study is similar to other studies of healthy older adults (e.g., Schmitter-Edgecombe et al., 2011), it is important to note that much of the variance in the functional measures remained unaccounted for. Despite attempting to control for the role of processing speed in the traditional measures by parsing out the speeded processing task components from the executive components (e.g., B-A), it is likely that a large processing speed component remained. This may be particularly relevant for older adults as processing speed frequently declines with advancing age even in cognitively HOAs. Also, this may be an additional reason for the significant correlations between the traditional measures as well as the variance accounted for by the traditional measures across multiple functional measures compared to the process pure measures.

Much of the literature has purported executive functioning to be a strong predictor of everyday functioning. However, our findings from the regression analyses suggest that at least with cognitively HOAs, executive functioning may not be as strongly associated with everyday functioning as previously believed, or that executive functioning measures are still not sensitive enough to capture a significant amount of the variance. Thus, caution is needed when making predictions about the quality of everyday activity completion in cognitively healthy older adults from performances on executive function measures. Future work is also needed to better understand noncognitive and other cognitive correlates (e.g., social, physical, psychiatric, behavioral, environmental, and demographic factors) and their impact on the relationship between cognition and everyday functioning (e.g., direct, additive).

Regarding limitations, our sample was highly educated and predominantly Caucasian. Furthermore, as variance in neurocognitive and functional status measures tends to be more constricted in cognitively healthy samples, these findings cannot be generalized to neurologic populations, and future research is needed. Given that a large number of regression analyses were performed without adopting a more conservative alpha level, some of the findings could be significant by chance and replication of these findings is warranted. Findings from the regression analyses were also limited by sample size, the limited battery of neuropsychological tests administered, and the specific neuropsychological measures chosen as the predictor variables to represent the cognitive constructs. Although well-replicated measures of executive processes were chosen, there are no agreed-upon standard measures, and it is possible that a different pattern of correlates may have emerged from completion of different executive functioning tests of the same subcomponent or with different psychometric properties. In addition, other executive processes (e.g., flexibility and access to long term memory, planning, dual tasking/divided attention, and judgment) have also been considered important subcomponents of executive functioning (e.g., Adrover-Roig, Sese, Barcelo, & Palmer, 2012; Fisk & Sharp, 2004; Brandt et al., 2009), and models considering these will be important in future research. In addition, although participants in this study were generally in good physical health, non-cognitive physical limitations that might limit everyday functioning (e.g., mobility issues) should be better assessed in future studies.

In this study, age-related differences were found on executive functioning subcomponent abilities and performance-based functional measures. For the older adults, reduced updating abilities were differentially related to poorer performance on two performance-based measures, although the updating measures differed across the functional status measures. Poorer switching abilities were related to problems on the informant-report and problem-solving measures. Inhibition was not a significant predictor of functional abilities. These data suggest that switching and updating abilities may differentially contribute to the age-related decline of everyday functioning in HOAs. After controlling for age and education, the traditional, but not process pure, executive function measures explained a significant amount of variance in the informant-report and both performance-based measures. The traditional executive function measures were likely capturing additional cognitive abilities as well as lower-level within domain abilities. Our data suggest that the contribution of executive functioning to everyday functioning in cognitively healthy older adults when measured with more process pure measures was not as strong as hypothesized. Additional research is needed to determine the value of more process pure measures, compared to more traditional measures, in neuropsychological assessment and the prediction of functional abilities in older adults.

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Table 1

Demographic Data for the Younger and Older Adult Groups

	Younger adults $N = 70$[a]		Young-old HOA $N = 45$		Old-old HOA $N = 25$			
Variable or test	*M*	*SD*	*M*	*SD*	*M*	*SD*	*F*	
Age	20.59	2.53	67.53	4.19	78.84	3.33	1387.17**	YA<YO<OO
Range	18 – 28		61 – 74		75 – 87			
Education	14.94	.93	17.11	2.37	17.00	2.89	5.38*	YA<YO=OO
Gender	13 F, 4 M		32 F, 13 M		13 F, 12 M			

Note. [a]*n* = demographic data for 17 participants.
*$p < .01$. **$p < .001$

Table 2

Mean Summary Data for the Process Pure and Traditional Executive Function, and Neuropsychological Measures for the Younger and Older Adult Groups

	Younger adults N = 70		Young-old HOA N = 45		Old-old HOA N = 25			
Test	*M*	*SD*	*M*	*SD*	*M*	*SD*	*F*	
Process pure								
Antisaccade	80.05	13.25	77.86[a]	13.34	66.58[b]	16.76	28.08***	YA>YO>OO
Keep Track Task	22.16	2.32	20.31	2.18	16.76	4.27	36.43***	YA>YO>OO
Number Letter Task[t]	.65[d]	.36	.92[c]	.40	1.02[b]	.34	12.77***	YA>YO=OO
Traditional								
Hayling[t]	7.06	16.53	25.30[c]	23.39	31.16	22.96	18.48***	YA>YO=OO
Reading Span	43.89	6.45	40.62	7.01	34.12	8.21	18.25***	YA>YO>OO
Trails B[t]	25.76[g]	15.45	37.49[a]	19.63	69.16	58.84	13.69***	YA=YO>OO
Neuropsychological								
MAS delayed prose	6.13[i]	1.41	6.91	1.10	5.92	1.50	5.46**	YA=YO>OO
Boston Naming Test	50.33[i]	9.22	58.14[c]	2.29	56.48	2.99	16.98***	YA<YO=OO
Facial Recognition Test	48.07[i]	3.26	48.02	3.75	47.32	3.75	.33	

Note. MAS = Memory Assessment Scale.
[a]*n* = 43. [b]*n* = 24. [c]*n* = 44. [d]*n* = 69. [e]*n* = 67. [f]*n* = 68. [g]*n* = 37. [h]*n* = 15. [t]Trails B-A; higher scores represent poorer performance.
***p < .001.

Table 3

Mean Summary Data for the Everyday Functioning Measures for the Older Adult Groups

	Young-old HOAs *N* = 45		Old-old HOAs *N* = 25			
Everyday functioning measure	*M*	*SD*	*M*	*SD*	*t*-test	Cohen's *d*
Self-report IADL-C[t¥]	.11[d]	.11	.12[f]	.10	-.46	.10
KI-report IADL-C[t¥]	.14[e]	.17	.16[g]	.20	-.34	.11
UPSA	86.53	8.10	80.32	11.69	2.62*	.62
EPT	25.04	2.33	22.00	5.12	3.38**	.76

Note. IADL-C = Instrumental Activities of Daily Living: Compensation Scale. KI = knowledgeable informant. UPSA = UCSD Performance-Based Skills Assessment-Brief. EPT = Everyday Problems Test.
[a]*n* = 63. [b]*n* = 52. [c]*n* = 68. [d]*n* = 40. [e]*n* = 31. [f]*n* = 23. [g]*n* = 21. [t]Higher scores represent poorer performance. [¥]Log-transformed total score.
*$p < .05$. **$p < .01$.

Table 4

Intercorrelations Amongst Process Pure and Traditional Executive Function Measures for Older Adults

	1.	2.	3.	4.	5.	6.	7.	8.	9.
Process pure									
1. Antisaccade	-	.27[a]	-.10[b]	-.15[c]	-.36[b]*	.19[a]	.05[a]	.24[a]	.19[c]
2. Keep Track Task		-	-.30[d]	-.13[e]	-.43[d]*	.53*	.23	.09	.30
3. Number Letter Task[t]			-	.14[a]	.23[c]	-.29[d]	-.13[d]	-.02[d]	-.08[a]
Traditional									
4. Hayling[t]				-	.42[d]*	-.31[e]*	.06[e]	.02[e]	-.09[d]
5. Trails B[t]					-	-.53[d]*	-.17[d]	-.24[d]	-.13[a]
6. Reading Span						-	.36*	.01	.43[e]*
Neuropsychological									
7. MAS delayed prose							-	.09	.30[e]
8. Facial Recognition Test								-	.18[e]
9. Boston Naming Test									-

Note. MAS = Memory Assessment Scale.
[a]$n = 67$. [b]$n = 65$. [c]$n = 66$. [d]$n = 68$. [e]$n = 69$. [t]Higher scores represent poorer performance.
*$p < .01$.

Table 5

Intercorrelations Amongst Everyday Functional Measures for the Older Adult Group

	Self-report IADL-C	KI-report IADL-C	UPSA total	EPT
Self-report IADL-C[t¥]	-	.17[a]	-.19[b]	.03[c]
KI-report IADL-C[t¥]		-	-.14[d]	-.26[e]
UPSA total score			-	.50[f]*
EPT				-

Note. IADL-C = Instrumental Activities of Daily Living: Compensation Scale. KI = knowledgeable informant. UPSA = UCSD Performance-Based Skills Assessment-Brief. EPT = Everyday Problems Test.

[a]*n* = 46. [b]*n* = 63. [c]*n* = 61. [d]*n* = 52. [e]*n* = 51. [f]*n* = 68. [t]Higher scores represent poorer performance. [¥]Log-transformed total score.

$*p < .001$.

Table 6

Correlations Between Everyday Functioning Measures with Demographics, Process Pure, Traditional, and Neuropsychological Predictors for the Older Adult Group

	Self total[at¥]	KI total[bt¥]	UPSA total[c]	EPT[d]
Demographics				
Age	.08	.13	-.33**	-.43***
Education	-.25*	-.20	.08	.42***
Process pure				
Antisaccade	.04	-.10	.18	.21
Keep Track Task	-.03	-.06	.33**	.45***
Number Letter Task[t]	.13	.05	-.32**	-.11
Traditional				
Hayling[t]	.04	.21	-.08	-.12
Reading Span	-.09	-.12	.53***	.51***
Trails B[t]	.10	.46**	-.45***	-.66***
Neuropsychological				
MAS delayed prose	-.11	.03	.35**	.42***
Facial Recognition Test	-.14	.00	.22	.31*
Boston Naming Test	-.01	-.02	.23	.40**

Note. MAS = Memory Assessment Scale. IADL-C = Instrumental Activities of Daily Living: Compensation Scale. KI = knowledgeable informant. UPSA = UCSD Performance-Based Skills Assessment-Brief. EPT = Everyday Problems Test.

[a]*n* = 60 – 63. [b]*n* = 49 – 52. [c]*n* = 67-70. [d]*n* = 65 – 68. [t]Higher scores represent poorer performance. [¥]Log-transformed total score.

**p* < .05. ***p* < .01. ****p* < .001.

Table 7

Summary of Hierarchical Regression Analyses for the Process Pure, Traditional, and Neuropsychological Predictors of Everyday Functioning Measures for the Older Adult Group

	Everyday Functioning Measures			
Variables	Self total[t¥]	KI total[t¥]	UPSA total	EPT
Process Pure				
Model 1				
Age	.00	.00	-.48*	-.22***
Education	-.01	-.02	.29	.60***
R^2	.07	.07	.11	.32
F for R^2	2.13	1.58	3.71*	14.17***
Model 2				
Age	.00	.00	-.19	-.16*
Education	-.01	-.01	.10	.58**
Antisaccade	.00	.00	.06	.00
Keep Track Task	.01	.01	.49	.30*
Number Letter Task[t]	.04	.00	-5.86	.86
Change in R^2	.06	.02	.09	.05
Total R^2	.13	.08	.20	.37
Traditional				
Model 1				
Age	.00	.00	-.50**	-.25***
Education	-.01	-.01	.35	.57**
R^2	.07	.05	.12	.35
F for R^2	2.24	1.11	4.36*	16.86***
Model 2				
Age	.00	.00	-.04	-.10
Education	-.01	.00	-.15	.36*
Hayling[t]	.00	.00	.06	.02
Reading Span	.00	.01	.54**	.08
Trails B[t]	.00	.00**	-.06	-.05***
Change in R^2	.00	.21*	.23***	.19***
Total R^2	.07	.26	.35	.54
Neuropsychological				
Model 1				
Age	.00	.00	-.49**	-.24***
Education	-.01*	-.01	.26	.60***
R^2	.08	.05	.12	.35
F for R^2	2.62	1.37	4.29*	17.56***
Model 2				
Age	.00	.01	-.33	-.14***

Education	-.01*	-.01	.13	.54***
MAS delayed prose	-.01	.02	1.59	.52
Facial Recognition Test	.00	.00	.32	.15
Boston Naming Test	.01	.00	.07	.21
Change in R^2	.03	.01	.06	.09*
Total R^2	.11	.07	.18	.44

Note. Age and education were entered in Block 1. MAS = Memory Assessment Scale. IADL-C = Instrumental Activities of Daily Living: Compensation Scale. KI = knowledgeable informant. UPSA = UCSD Performance-Based Skills Assessment-Brief. EPT = Everyday Problems Test.

[t]Higher scores represent poorer performance. [¥]Log-transformed total score.

*p < .05. **p < .01. ***p < .001.