Examining Subcomponent Processes of Executive Functioning in Older Adults

By

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Submitted to the graduate degree program in Clinical Psychology and the Graduate Faculty of the University of Kansas in partial fulfillment of the requirements for the degree of Master of Arts.

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Date Defended: July 17, 2017

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Abstract

Executive Function (EF) is a broad construct used to describe higher-order cognitive abilities used to achieve a goal. Standardized measurements used to evaluate EF abilities in older adults are designed to assess for EF as a unitary complex construct, but may be insufficient in capturing the subcomponent cognitive processes that make up the complex nature of EF. The Unity/Diversity framework is a theoretically derived model of executive function that helps to parse out complex executive function derivatives into specific indices of ability with the use of latent construct analyses (Baddeley & Logie, 1999; Miyake et al., 2000). To date, one study has been published on the use of the unity/diversity framework to examine subcomponent processes of EF in older adults (Vaughan & Giovanello, 2010). In the current study, we aim to use a similar methodological approach as Vaughan and Giovanello (2010) to investigate subcomponent processes of EF in a sample of healthy older adults. Participants included 91 older adults who ranged between the ages of 66 and 90 (mean age= 73.3, SD = 6.34). Participants were excluded if they reported a history of neurological disorders, any current major medical conditions, and any psychiatric conditions or use of medications for psychiatric conditions. Findings suggest that the three-factor hypothesized model did not fit the covariance data of our sample as demonstrated by with significant chi-square results, X^2 (17, *N*=91) = 36.49, *p* = .004. Findings in our studies were not consistent with those of other studies and some limitations of the current study, which may have influenced the findings, are considered.

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Chapter 1
Introduction

Executive Function (EF) is a broad construct used to describe higher-order cognitive abilities used to achieve a goal. These cognitive abilities include problem-solving, inhibiting, planning, and organizing to adapt behavior as a response to changes in the environment. Executive Functions are cognitions enable us to plan, initiate, execute and mentally organize information in order to produce goal-directed behavior (Jurado & Rosselli, 2007). Maturation of the frontal lobes, a process that begins as early as infancy, coincides with the adeptness of EF (Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001). Late-life declines in EF are diagnostic of frontal lobe dysfunction and symptomatic of neurodegenerative disease (Castel, Balota, & McCabe, 2009; Hedden & Yoon, 2006; McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010). Age-related EF changes independent of a neurodegenerative disease process are not well understood.

Age-related EF decline in performance on neuropsychological tests and evidence from functional neuroimaging studies support the frontal lobe hypothesis of cognitive aging (West, 1996). An important assumption of the frontal lobe hypothesis of aging is that cognitive abilities of the prefrontal cortex will decline at an earlier age compared with cognitive abilities of other brain regions (West, 1996). Morphological studies have shown that the prefrontal cortex is impacted with greater age-related neurobiological changes compared with other brain regions (Goldman-Rakic and Brown, 1981; Haug and Eggers, 1991). These neuroanatomical changes have been linked to specific EF deficits such as inhibitory processes (Hasher and Zacks, 1988), task-related processing (Fuster, 1980; Goldman-Rakic, 1987), and processing speed (Salthouse, 1996). It is well documented that these are not the only cognitive processes associated with the prefrontal cortex and decline in EF is a result of several cognitive abilities rather than a single process.

One of the criticism of these additional theories stemming from the frontal lobe hypothesis is a weak discrimination between decline in EF abilities and general cognitive abilities. Subsequent research proposed that the frontal lobe hypothesis is too simplistic in capturing the complexity of our current understanding of EF and further raised concern about EF measurement in older adults (Crawford & Channon, 2002; De Luca et al., 2003; Greenwood, 2000). This has been followed by additional theories of executive processes such as updating (Miyake et al., 2000), focus-switching (Verhaeghen & Basak, 2005), and task-switching (Salthouse, Atkinson, & Berish, 2003) which introduce the complexity of EF and may improve understanding of differential decline in EF in normal and pathological aging. Additionally, these theoretical contributions provide opportunities to study complex EF beyond the traditional neuropsychological instruments currently available.

Traditionally, standardized measurements evaluate EF performance have been used for predicting functional abilities among older adults (Bell-McGinty, Podell, Franzen, Baird, & Williams, 2002; Martyr & Clare, 2012), evaluating declines associated with age-related white-matter degradation (Van Petten et al., 2004), and examining age-related cognitive changes (Dahlin, Nyberg, Bäckman, & Neely, 2008). Valuable information about the relationship between executive functions and adaptive behaviors among older adults as well as the age-related cognitive declines older adults experience in these domains resulted from the use of these measurements. Standardized measurements are designed to assess for EF as a unitary complex construct, but may be insufficient in capturing the subcomponent cognitive processes that make up the complex nature of EF. We understand EF as a representation of a complex set of interrelated cognitive processes that are separable for which standardized measurements are not designed since they are designed to assess the overall functional abilities of EF (Miyake et al., 2000). These standard multimodal neuropsychological tests of “frontal lobe” functioning (e.g. Wisconsin Card Sorting Task) are complex tasks that are difficult for the older population to complete and yield impure indices of executive function. The combination of these psychometric challenges provides an intriguing impetus for investigating the use of executive function tasks that are simple and unimodal.

The Unity/Diversity framework is a theoretically derived model of executive function that helps to parse out complex executive function derivatives into specific indices of ability with the use of latent construct analyses (Baddeley & Logie, 1999; Miyake et al., 2000). There is strong empirical evidence in support this model in older adults (Fisk & Sharp, 2004; Hedden & Yoon, 2006; Hull, Martin, Beier, Lane, & Hamilton, 2008; Salthouse et al., 2003; Vaughan & Giovanello, 2010) by using simple computer-based tasks to measure the *diversity* of executive function (inhibition, shifting, updating) and a common underlying *unity* of ability. The use of this framework has given researchers an opportunity to investigate EF using a comprehensive approach that allows for understanding of the individual cognitive processes and EF as an integration of these interconnected cognitive processes.

To date, one study has been published on the use of the unity/diversity framework to examine subcomponent processes of EF in older adults (Vaughan & Giovanello, 2010). The researchers replicating the task developed by Miyake and colleagues (2000) to examine the relationship between subcomponent processes of EF and independent living skills. In the current study, we also aim to examine the subcomponent processes of EF in a sample of healthy older adults with slight differences in task selection. In an effort to establish a solid foundation for the current study, the following sections draw on a number of distinct areas in the literature. First, research investigating the shortcomings of using standardized measures of executive function will be discussed and research on the use of the unity/diversity model to measure executive functions will be reviewed.

Executive Functions in Older Adults

Extensive use of standardized measurements for EF in older adults presents a challenge for isolating subcomponent EF processes. These challenges are often embedded in the design of the measurements rather than the methodology of the research studies (e.g. demand of motor dexterity required to complete the tasks). Previous research has often utilized measurement that require some level of motor intactness, such as the Trail Making Test (Bell-McGinty, Podell, Franzen, Baird, & Williams, 2002; Cahn-Weiner, Boyle, & Malloy, 2002; Sudo et al., 2015). The Trail Making Test is a commonly used measure to assess inhibition and switching (Hodges, 1994), however, given the rate of motor concerns that occur in this population, it is important to examine how such limitations influence the ability to measure these executive processes for which the measure was designed. Given the interference of physical limitations experimental research has emphasized the use of computers as a means minimize the impact of these limitations (Miyake et al., 2000).

Furthermore, standardized measurement of EF presents a challenge when examining component processes of EF and the impact of EF on other cognitions and behaviors. Variability in performance-based conclusions sheds light on the impurity of measuring EF, however, assesses EF as a unitary construct well (Amieva, Phillips, & Sala, 2003; Carlson et al., 1999; Farias et al., 2009). Furthermore, differential findings of performance on EF measures and correlation with adaptive behaviors (Carlson et al., 1999; Johnson, Lui, & Yaffe, 2007) has provided useful information about how EF is to be examined in the elderly population.

Unity and Diversity Framework of Executive Function

Theoretical debate about the construct validity of EF and its unitary and non-unitary components has been explored by researchers in an attempt to understand the cognitive abilities that makeup EF (Duncan Roger Johnson Michaela Swale, Duncan, & Johnson; Miyake et al., 2000; Salthouse, 2005). Much debate has centered on understanding the convergent and discriminant validity of EF. Miyake et al. (2000) proposed that there are unique separable processes (have discriminant validity) which he referred to as diversity of EF. He proposed that these diverse subcomponent processes of EF are correlated to each other such that a unitary construct exists (have convergent validity). However, Salthouse (2005) proposed that processing speed and general reasoning abilities better explain the variance commonly found among EF constructs while others have suggested that fluid intelligence better explain EF as a construct (Burgess, 1997; Duncan & Burgess). Other researchers have attempted to explain EF with a unitary process or limited subcomponent processes (Bell, 2000; Cahn-Weiner et al., 2002). Much of this type of research has relied on the use of latent variable analysis to parse out these subcomponent processes of EF (Fournier-Vicente, Larigauderie, & Gaonac'h, 2008; Friedman & Miyake, 2004; Huizinga, Dolan, & van der Molen, 2006; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003; Miyake et al., 2000; van der Sluis, de Jong, & van der Leij, 2007).

Miyake et al. (2000) used Confirmatory Factor Analyses (CFA) to examine the construct validity of EF in younger adult and concluded that there are separable processes of EF that together makeup the EF construct, which he termed the unitary/diversity model of EF. One of the major aims of his research was to examine the subcomponent processes, which he specified as three separable units (updating, switching, and inhibition). Miyake et al. (2000) found a three-factor model of EF (updating, switching, and inhibition) provided a best fit for the data after comparing the model to a two nested model (one factor model and two factor mode). Fournier-

Vicente et al. (2008) similarly used latent variable analyses to examined the construct validity of EF in younger adults (mean age = 23) and found that a five-factor model of EF provided the best fit for the data after the model to two nested models (a one factor model and a six factor model). The authors concluded that subcomponent processes such as shifting, selective attention, retrieval, dual-task coordination, and processing coordination (verbal and visuospatial) made up the five-factor model. It is important to note that Fournier-Vicente and colleagues (2008) used different tasks to assess the unity/diversity framework of EF than those used by Miyake and colleagues (2008). Only one task (number-letter) that is the same in these studies and both research teams found that this task measures shifting abilities. Furthermore, Miyake et al. (2008) include processing speed in their analyses while Fournier-Vicente and colleagues (2008) found two-factors related to processing speed in their model.

Salthouse (2005) also examined construct validity of EF by examining the relationship between five cognitive abilities and standardized neuropsychological measurements of EF. This study was conducted in a sample of younger adults and older adults (age range 19-93 years). Salthouse (2005) used CFA to examine how five cognitive abilities (reasoning, spatial abilities, memory, speed, and vocabulary) are related to EF by assessing the shared variable between the cognitive abilities and EF variables. Findings show that the cognitive abilities did to account for all the variance in EF and a moderate amount of variance remained unexplained. This suggests that these cognitive abilities alone do not explain EF and other aspects of cognitive abilities should be explored to assess subcomponent processes of EF. Salthouse (2005) expanded the research on this to older adults. Some research has also examined subcomponent processes of EF in children (Huizinga et al., 2006; Lehto et al., 2003). Both studies examine the unity/diversity model of executive function with Lehto et al. (2003) suggesting a three-factor model of EF in children between the ages of 8-13. They found that the three-factor model (working memory, shifting, and inhibition) best fit the data while Huizinga et al. (2006) found a two-factor model (working memory and shifting) best fit the data.

There is a divide in the research on executive function processes with some research suggesting a two-factor model in children (Lehto et al., 2003) or a more complex three-factor model when assessing this in children and adolescents (Huizinga et al., 2006). These models become even more complex when they are examined in young adults, some suggesting that a five-factor model of executive function is present (Fournier-Vicente et al., 2008; Miyake et al., 2000). There is only one study to date that has examined subcomponent processes in healthy older adults using the computerized tests that were developed by Miyake et al. (Vaughan & Giovanello, 2010). The findings from this study suggest that the same three-factor structure of inhibition, task-switching, and updating holds true for healthy older adults when examining subcomponent processes of EF. Vaughan and Giovanello (2010) used the same study design to that of Miyake et al. (2000) when they replicated a three-factor model of EF in older adults.

Chapter 2

The Current Study

In the current study, we aim to investigate subcomponent processes of EF in a sample of healthy older adults. Previous research has criticized the use of standardized neuropsychological measures to assess EF because of the complex nature of these tasks as well as the impurity of information about "frontal lobe" abilities. Standardized measurements provide valuable information for understanding EF as a complex construct; however, critics of these measures posit that standardized measurements lack information on separable component processes of this domain. Thus, in the current study the aim is to examine the separable component processes using a set of computerized-tasks previously used in research studies examining this same topic.

Latent Variable Component Processes of EF in Older Adults

Question: We are interested in examining the construct validity of EF in healthy older adults. The main question posed is what is the underlying factor structure on EF in healthy older adults? The construct validity of EF shows a three-factor model in young adults and healthy older adults using the same methodological research paradigm (Friedman & Miyake, 2004; Miyake et al., 2000; Vaughan & Giovanello, 2010). While some inconsistent findings exist in the models (three-factor model, two-factor model, and five-factor model), the differential use of tasks for deriving these models could explain some of this variability. However, one previous study has proposed a similar three-factor model of EF that has been proposed by Miyake and colleagues (Vaughan & Giovanello, 2010). The experimental design of the current study is similar to the one used by Vaughn and Giovanello.

Hypothesis: We aim to test Miyake's 3-factor model compared to potentially more parsimonious one-factor and two-factor models. We hypothesize that a three-factor model will show a best fit for subcomponent process of EF in our sample.

Chapter 3

Method

Participants

Participants included 91 older adults who ranged between the ages of 66 and 90 (mean age= 73.3, SD = 6.34). Participants included 39 older adults who were recruited from the research participant registry at the University of Kansas Alzheimer's Disease Center (KUADC) and 51 older adults from an existing database (data collected at the KUADC in 2012). University of Kansas and University of Kansas Medical Center joint Institutional Review Board approved the study. All participants were consented and those participants recruited through the participant registry at the KUADC were compensated ten dollars for their time and participation.

Eligibility requirements for all participants included normal or corrected vision and normal or corrected hearing. Participants were excluded if they reported a history of neurological disorders, any current major medical conditions, and any psychiatric conditions or use of medications for psychiatric conditions. Participants from the current study (*N*=39) showed negative results from Positron Emission Tomography (PET) scan. This suggests that these participants show minimal amyloid plagues, which is demonstrative of a healthy aging process. The relationship between amyloid plaques and health-related cognitive changes is beyond the scope of this study. Due to the incomplete nature of amyloid information for participants, this information was not part of the analyses. It is reported in this section as a demographic variable only.

Measures:

Antisaccade Task (Inhibition Construct). Participants are instructed to fix their gaze on a cue sign ("+") in the center of the screen when it appears. A small black square flashes on the left or right side of the screen appears after the initial sign disappears followed by a number (range 1-9). In the first block of the task, the number appears in the same location on the screen as the cue, while in the last three blocks the number flashes on the opposite side of the screen (e.g. if the number flashes on the left side, the number will flash on the right side). Participants are instructed to respond with the number that appears on the screen as quickly and accurately as they can. The number is presently for several seconds before being replaced with a large grey square. The proportion of target trials that were answered correctly is reported as the dependent variable and this reporting is a percent value (Miyake et al., 2000).

Spatial Stroop Task (Inhibition Construct). Participants are instructed to gaze at a sign ("+"). A set of left-or-right pointed arrows ('<<<<<' or '>>>>>') appears on the screen following the sign. The arrows are located on either the left or right side of the screen and the side on which the arrows appear either match or do not match the direction the arrows are pointing. Stimulus is presented for 2 seconds before it disappears from the screen. Participants are instructed to respond (using a button box) to the direction the arrows are pointing while ignoring the location of the arrows on the screen (e.g. if left-pointing arrows participants must press the left button on the button box, and for right-pointing arrows they must press the right button). The value for the dependent variable was the Reaction Time (RT) difference between the congruent and incongruent trials. This method of deriving the dependent variable is same as used by Miyake et al. (2000) in his verbal stroop task.

Spatial 2-back (Updating Construct). Scattered arrangement of identical squares or boxes were first displayed on the screen the participant to which the participant was asked to fixate. This was followed by one of the boxes appearing blackened which was followed by a new box that was blackened after a 2 second interval. Participants are asked to keep track of which of the two boxes was recently blackened and then are asked to respond as accurately as possible. The participant must selected whether the current black box is the same as the black box two presentations back. Participants respond for each box presented as either the same (yes) or not the same (no). The first two boxes in each series of presentations are always "no" since there has not yet been a two-back black box with which to compare the current box. The proportion of target trials that were answered correctly is reported as the dependent variable and this reporting is a percent value (Miyake et al., 2000).

KeepTrack (Updating Construct). Participants are first shown target categories from six possible categories (animals, colors, countries, distances, metals, and relatives). Fifteen words are then presented individually (including 2-3 examples from each of the six categories) and in random order. Each words is presented for 1500 ms as the target categories remain present at the bottom of the screen. Participants are asked to remember the last word in each of the target categories and say these words aloud at the end of the trial. There were three trials with four target categories and three trials with five target categories. The proportion of correctly recalled words was entered in a spreadsheet. These data was accumulated across the trials the proportion correctly recalled is reported as the dependent variable (Miyake et al., 2000).

Letter Memory (Updating Construct). In this task (adapted from Morris & Jones, 1990) several letters are presented serially with each letter being presented for 2000 ms. The participant is asked to recall the last 4 letters that were presented in the list. The participants needed to rehearse aloud the last 4 letters by mentally adding the most recent letter presented and dropping the 5^{th} letter and continuously saying a string of letters that consisted of 4 letters. The participants completed 12 trials for a total of 48 letters. The proportion of letters correctly recalled was taken as the dependent variable and was presented as percent correct (Miyake et al., 2000).

Number-Letter (Shifting Construct). The display shows a box with four quadrants. In each trial of the task, a number ranging from 1-9 is paired in a quadrant with a letter that is either a vowel (A,E,I,U) or a consonant (G,K,M,R). In the first part of the task, the number/letter pairs appear only in the top two quadrants of the display. Participants must pay attention to the number in the pair; if the presented number is odd they must press the left button on the button box, and if it is even they must press the right button. In the second part of the task, number/letter pairs appear only in the bottom two quadrants and participants must pay attention to the letter in the pair. If the letter is a consonant, they must press the left button, and if it is a vowel, they must press the right button. In the last three blocks of the task, the number/letter pairs may appear in any of the four quadrants. If a number/letter pair appears in one of the top two quadrants participants must respond to the number, while if a number/letter pair is displayed in one of the bottom two quadrants they must respond to the letter. In these blocks, the quadrant in which the next number/letter pair will appear becomes outlined in bold. This acts as a cue to the location of the pair before it appears. The difference in RT of the trials that required a mental shift (trials from the upper left and lower right quadrants) and the average RT from the trials that did not require a mental shift was derived as the dependent variable and reported as RT (Miyake et al., 2000).

Category Switch (Shifting Construct). Participants must categorize presented words based on the symbol that appears. In the first block, a heart symbol precedes each presented word and indicates to participants that they must respond to whether the word represents something that is living or nonliving. If it is living, they must press the left button on the button box, and if it is nonliving they are to press the right button. In the second block the same words appear as in the first, however the symbol is instead a pair of intersecting arrows and indicates to participants that they must decide whether the presented word represents something that is smaller or larger than a soccer ball. If the word represents something smaller than a soccer ball they must press the left button, and if it is bigger than a soccer ball they are to press the right button. In the final two blocks of the task, the symbol before each presented word is either a heart or a pair of intersecting arrows, indicating to participants that they should respond to whether it is living/nonliving or smaller/bigger than a soccer ball, respectively. The difference in RT of the trials was derived as the dependent variable and reported as RT (Miyake and Friedman, 2012).

Color-Shape (Shifting Construct). Colored shapes are presented on the screen one at a time. Each presented shape is either a circle or a triangle and colored red or green. In the first block of the task, the letter "C" appears before each shape and cues participants to respond to the color of the shape; for red-colored shapes participants must press the left (red-colored) button on the button box, while for the green-colored shapes they must press the right (green-colored) button. In the second block, the letter "S" acts as a cue and participants must respond to the shape rather than the color of the presented object; for circles they must press the left button and for triangles the right button. In the two last blocks, the letter cue varies. A "C" letter cue means the participants must to the color (red or green) of the presented shape, while an "S" cue means they must respond to the shape (circle or triangle). The difference in RT of the trials was derived as the dependent variable and reported as RT (Miyake and Friedman, 2012)

Procedure

Each participant completed the computerized cognitive battery in a single session. The session was 3 to 4 hours in duration. All participants met eligibility criteria and consented prior to the start of the study. The eight executive function tasks were administered in a fixed order to all participants. The order of the administration for each participant is as follows: Antisaccade

(Inhibition), Spatial 2-back (Updating), Color-Shape naming (Shifting), Letter Memory (Updating), Number-Letter sequencing (Shifting), Spatial Stroop (Inhibition), KeepTrack (Updating), Category Switch (Shifting). Participants were given 10-minute breaks throughout the testing session as this was on an as needed basis with some participants needing more breaks.

Chapter 4

Analytic Strategy

Analyses were conducted in the Statistical Package for the Social Sciences (SPSS) and in the added SPSS module Amos. Prior to conducting Confirmatory Factor Analysis in Amos (CFA) the data was evaluated for outliers, non-linearity and non-normality patterns. For each model, we examined specification and identification of the model, estimates of the model, and model fit.

The measurement models for EF were first specified based on well-grounded prior empirical evidence and theory. Each model was identified by defining the metric of the latent variables. This was accomplished by fixing the variance of one observed measure of each factor to a fixed value (this was set to 1.0). Factor loadings between measured indicators and between latent variables were allowed to vary without constraint. The fitting function used to estimate the model was Maximum Likelihood (ML). ML is dependent on several key assumptions (1) sufficient sample size (2) use of indicators that approximate interval-level scales and (3) multivariate normality. ML is relatively robust to mild violations in these assumptions (Tabachnick & Fidell, 2013) and is also recommended for the use of continuous data (Schumacker and Lomax, 2004).

After all the data was input, model evaluation was completed by examining overall fit of the model. Model fit measures whether the sample variance-covariance matrix is similar to the population variance-covariance matrix. There are several criteria to assess model fit. First, a non-statistical significance of the chi-square test. A non-significant chi-square value indicates that the sample covariance matrix and the specified model covariance matrix are similar (not statistically different) and is indicative of a good model fit. The Root Mean Square Error of Approximation

(RMSEA) is a supplementary comparative statistical analysis to examine that allows researchers to asses for good model fit. RMSEA values less than or equal to .06 indicate good model fit. Browne and Cudeck (1993) suggested that RMSEA values less than .08 suggest adequate model fit while MacCallum et al. (1996) further elaborated on this topic to suggest that RMSEA values that range between .08-.10 suggest a mediocre model fit.

It is recommended that other aspects of fit evaluation (parameter estimates) be evaluated to provide more specific information about the model fit (Brown, 2015). Therefore, we also examined the parameter estimates for each model. We examined the significance of each individual parameter estimate for examine its contribution to the model (values were significant at the .05 level). We also tested nested, one- and two-factor models by constraining the parameter at the value of 1.0. We examined the chi-square difference test to assess whether the nested models were significantly different.

In our study, we used confirmatory factor analysis (CFA) was used to examine the construct validity of EF in healthy older adults. We examined the separable (diverse) subcomponent process and the unitary nature of these processes of EF by measuring inhibition, task-switching, and updating. Using CFA as our statistical method, we examined the convergent and discriminant validity of EF as a theoretical construct with adjustment in measurement error and error in theory. First, the common factor model of EF was tested to ensure that all of the indicators (measured variables) loaded on the predictor variable. We did so by variance analyses (the variance accounted for by the factor) and unique variance analyses (combination of reliable variance that is specific to the indicator). Second, structural equation modeling was used to test the construct validity of EF. We did with model comparison between the parent three-factor model (inhibition, task-switching, and updating) and two possible nested models (two-factor model and one-factor model).

Chapter 5

Results

Findings from a one-factor model as shown in Figure 1 supports that the executive processes of inhibition, updating, and shifting are separable, X^2 (20, *N*=91) = 43.56, *p* = .002. The significant chi-square results suggest that this model did not fit our sample data and fit indices suggest a poor model fit (RMSEA = .11, CFI = .73). The model was tested by restricting all correlations between the latent variables to 1.0. Furthermore, all factor loadings were significant ($p < .05$) except for spatial two-back task ($p = .24$). Furthermore, the correlations between the individual subtests were in the small to medium range (.16 to .63). Overall, these findings suggest that a one-factor model is not a good fit for this data and while these processes measures a similar construct, they should be considered separately.

Findings from a three-factor model as shown in Figure 2 produced a significant chi-square results, X^2 (17, *N*=91) = 36.49, *p* = .004. These findings suggest that the three-factor hypothesized model did not fit the covariance data of our sample. Furthermore, results indicate that model indices suggest a poor model fit (RMSEA = .11, CFI = .77). Furthermore, the correlation between latent variables shifting and inhibition was significant ($p = .00$), however, the correlation between updating and shifting was not significant ($p = .35$) and the correlation between updating and inhibition ($p = .34$) was also not significant. Furthermore, shifting construct ($p = .02$) provided a significant contributor to overall executive functioning while inhibition was approaching significant variance ($p = .06$) and updating did not show significant variance on the overall model ($p = .61$). However, the correlations between the three latent variables (shifting, updating, and inhibition) were large (.61 to .87).

Additionally, three separate two-factor models were also estimated such that two of the three correlations were constrained at 1.0 to allow the other two latent variables to function in a nonconstrained manner. Findings from the two-factor model such that Shifting=Updating, X^2 (18, *N*=91) = 36.44, *p* = .006 (RMSEA = .10; CFI = .78). The results of the chi-square difference test between the three-factor model and this two-factor model (Shifting=Updating, Inhibition) was not significant, X^2 (1) = .012, *p* = .914 suggesting that the model fit for this two-factor model may also fit the data. Similarly, findings from the two-factor model such that Inhibition=Updating, X^2 (18, *N*=91) = 36.74, *p* = .006 (RMSEA = .10; CFI = .78). The results of the chi-square difference test between the three-factor model and this two-factor model (Inhibition=Updating, Shifting) was not significant, X^2 (1) = .309, *p* = .578 suggesting that the model fit for this two-factor model may also fit the data. However, the fit indices for each of these two-factor models are not strong.

Findings from the two-factor model such that Inhibition=Shifting, X^2 (18, *N*=91) = 50.57, *p* = .000 (RMSEA = .14; CFI = .62). The results of the chi-square difference test between the three-factor model and this two-factor model (Inhibition=Shifting, Updating) was significant, X^2 (1) = 14.14, *p* = .000 suggesting that the model fit for this two-factor model does not fit the data better compared to the three-factor model.

Chapter 6

Discussion

Our aim was to test Miyake's 3-factor model compared to potentially more parsimonious one-factor and two-factor models. We hypothesize that a three-factor model will show a best fit for subcomponent process of EF in our sample. Our findings from the CFA modeling suggest that EF is better understood as a non-unitary construct (separable components). Model fit was poor for a one-factor model, which suggests that EF is a construct that has distinct and yet convergent processes and EF should be examined through understanding these processes. These findings are consist with previous research on the diversity of EF in young adults (Miyake et al., 2000) as well as healthy older adults (Vaughan & Giovanello, 2010) and suggest that while these cognitive processes (inhibition, task-switching, and updating) assess EF abilities in general, these cognitive processes can be further divided into subcomponents. These findings have come for research studies designed to isolate subcomponent processes of EF with well-controlled methodological approaches. The results from this study suggest that EF is non-unitary construct, although the extent of the number of multi-faceted constructs remains to be tested. Miyake et al. (2000) examined inhibition, task-switching, updating as diverse processes of EF.

Furthermore, our findings show that the three-factor model produced a poor model fit compared to findings demonstrated in previous studies. We found moderate correlations between the latent variables [update-shift (-.61), update-inhibit (-.67), and shift-inhibit (.87)] which is similar to the findings reported by in previous studies examining these latent variables in healthy older adults. The authors similarly reported moderate correlations between the latent variables (update-shift (.83), update-inhibit (.57), and shift-inhibit (.71)). However, these authors also reported a good overall model fit with a three-factor model of EF in healthy older adults (Vaughan & Giovanello, 2010) which we did not find in our sample. Moderate to large correlations among the latent variables have been reported by other researches examining these functions in younger populations (Salthouse et al., 2003 reported .71-.94; Miyake et al., 2000 reported .42-.63). Miyake et al. (2000) similarly found a three-factor model fit best the understanding of subcomponent processes of EF.

The inconsistency in our findings compared to those of Vaughan and Giovanello (2010) who also examined latent variable analyses of EF in older adults may be in the use of scores to evaluate these latent constructs. The authors used incorrect response patterns (% incorrect, RT of incorrect response) while we used a correct response pattern (% correct, RT correct). We decide to use correct response pattern to be consistent with recommendations proposed by Miyake et al. (2000). It is important to note that Miyake et al. (2000) conducted his research in younger adults.

Hedden and Yoon (2006) examined subcomponent processes in older adults and found that updating and task-switching shared a large correlation (.92) and functioned better as a unitary construct. Thus, the authors reported that a two-factor model was a better model fit for EF in older adults. Our findings suggest that when task-switching and updating were examined as a unitary construct, the results suggest that the model worked similarly to that of a three-factor model. Our findings also show that when the updating and inhibition latent variables were examined as a unitary construct, the two-factor model also fit similarly to that of a three-factor model. While our findings are inconclusive in identifying which two of the three latent variable operate similarly, both options involved the latent variable updating. This is consistent with the reports by Hedden and Yoon (2006). We found similar results as Hedden and Yoon (2006) that the updating latent variable shares a large variance with task-switching in older adults. Furthermore, Miyake and Friedman (2017) recently reported that a two-factor model may be a better descriptor of EF.

Additionally, our findings suggest that the latent variable of updating also shares commonality with the inhibition latent variable such that a two-factor model that combines these two variable may explain EF in older adults. It is important to note that in our sample for both sets of combinations that the model fit indices were not strong and therefore interpretation of these two-factor model combinations should be considered with caution in our sample. These findings may suggest the change processes that occur to EF in the older population. Research has demonstrated an increase in white matter degradation in older adults, which may be indicated, of a ‘fusing’ of EF abilities or “dedifferentiation” of abilities as Hedden and Yoon (2006) noted. It may be indicative that areas associated with the frontal lobe was less efficacious at differentiating.

Findings in our studies were not consistent with those of other studies and some limitations of the current study, which may have influenced the findings, are considered. First, the sample size is below the typically recommended number of participants to run a CFA causing problem with statistical power. Previous research has recommended that a minimum of 100 participants (Schumacker & Lomax, 2004) are included in a CFA model. The proposed recommendation given because small sample sizes can lead to non-significant chi-square results independent of model fit. However, researchers (Hau & Marsh; 2001) have suggested that a minimum of fifty participants is sufficient to run a CFA and preserve statistical power. Second, our sample consists of the combination of two data set that were collected for two different studies. While this practice is not uncommon, it does introduce liability to the data including variability in the screening process used at these two time points, methodological variations, and variance in subject pool. In our about 50% of our sample particularly, we do not have information on current cognitive functioning as well as health-related and psychiatric-related concerns that could have impacted the performance on the this testing.

Future studies should continue to examine the multi-faceted dimensions of EF and explore additional subcomponent processes makeup EF in addition to the two- and three- factor models that we know as of currently. Additionally, functional imaging studies should be utilized to examine the correlational relationship between latent constructs and brain localization.

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Tables and Figures

Table 1

Fit indices for executive functions

Model	**df**	**X^2**	**RMSEA**	**CFI**
Three Factor Model	17	36.43, p=.004	.11	.77
One Factor Model	20	43.50, p=.002	.11	.73
Two Factor Model				
Inhibition=Task Switching	18	50.57, p=.000	.14	.62
Inhibition=Updating	18	36.74, p=.006	.10	.78
Task Switching=Updating	18	36.44, p=.006	.10	.78

Note. RMSEA = root mean square error of approximation; CFI= comparative fit index.

Table 2. Demographic characteristics of participants (N = 39)

Model	**Age**	**Education**	**MMSE**
Mean (SD)	73 (6.3)	16 (2.6)	29 (1.1)
Range	66-93	12-20	25-30

Figure 1. One- Factor Measurement Model of Executive Function

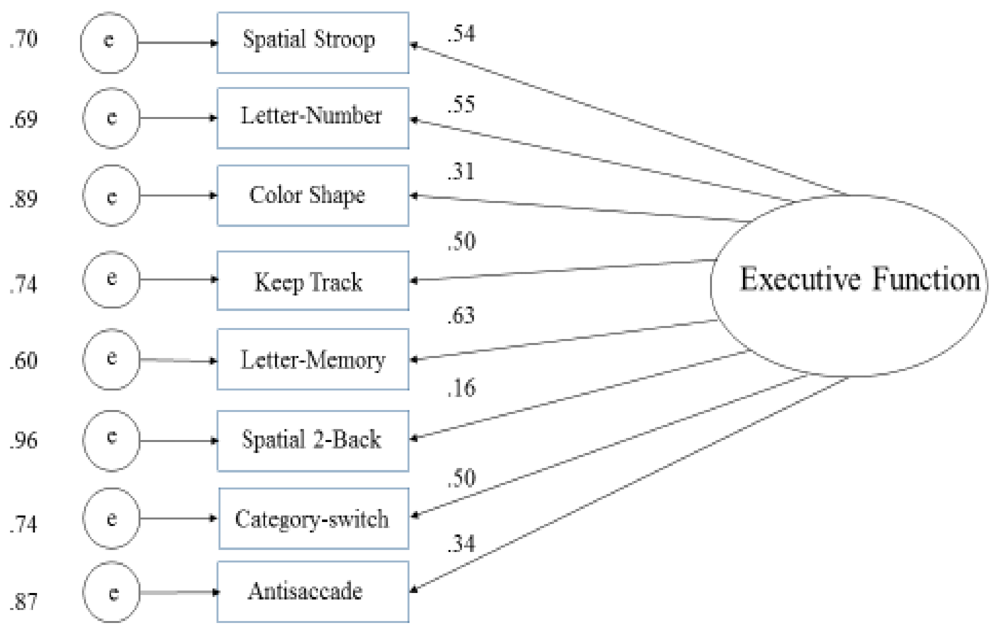

Figure 2. Three- Factor Measurement Model of Executive Function