ABSTRACT

SMITH, BRIAN THOMAS. The Effect of Situational and Individual Factors on Young and Older Adults' Cognitive Fatigue. (Under the direction of Dr. Thomas Hess.)

This study examines whether there are age differences in subjective and objective aspects and cognitive fatigue, and whether cognitive control beliefs and situational factors moderate the experience of fatigue. This study included a sample of 130 participants, 50 younger adults (18-20 years) and 80 older adults (64-85 years) equally split across genders. Participants performed the Attention Network Test for Interactions and Vigilance (ANTI-V), a measure that evaluates three separate components of the attention network. I was most interested in performance on the executive network as it was hypothetically most related to cognitive fatigue. In addition, I measured cognitive fatigue using both subjective (Piper Fatigue Scale-12; NASA-TLX) and objective measures (Systolic Blood Pressure Reactivity). Finally, I was interested in whether or not older adults responses to a fatiguing task depended on situational factors such as the time of day at which they were tested or individual difference factors such as their beliefs about their cognitive control. As in previous studies, older adults generally reported greater levels of fatigue and required more effort and workload to successfully complete the task than younger adults. However, there were very few significant fatigue findings in the objective measures. Control beliefs and time of day did have significant effects on individuals' responses to the task. The results suggest that the ANTI-V may not be a strong indicator of fatigue in high functioning older adults. Implications of the findings for control beliefs and time of day are also discussed.

The Effect of Situational and Individual Factors on Young and Older Adults' Cognitive Fatigue

by
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DEDICATION

To my wife, Layne, and my family for their constant and unwavering support. Thank you to all the faculty and staff of North Carolina State University for your training and advising.

BIOGRAPHY

Brian Thomas Smith graduated in 2009 from Elon University. While at Elon he was trained and advised by Dr. Amy Overman. After graduating with his B.A., he attended the University of North Carolina Wilmington. While there he worked with Dr. Karen Daniels and Dr. Jeff Toth. He graduated from UNCW with his M.A. of general psychology in 2011. From 2011-2016 Brian has attended North Carolina State University, where he has been advised by Dr. Thomas Hess.

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Age is associated with an increased experience of cognitive fatigue (Avlund, 2013). While there is no universally accepted conceptual framework or definition for cognitive fatigue (DeLuca, 2005), it typically refers to the temporary experience of mental exhaustion felt after performing an effortful cognitive task. An age-related increase in cognitive fatigue serves as a potential explanatory factor for the cognitive declines seen with aging and is included in some theoretical models. For example, Selective Engagement Theory (SET; Hess, 2014) assumes this experience of fatigue decreases older adults' motivation to engage their resources in cognitively demanding tasks. Yet, the research on older adults' response to cognitive fatigue is limited. Research on young and middle-aged adults has shown that personality factors such as conscientiousness (Matthews, 2009), extraversion, and styles of self-regulation (Schunk & Parjares, 2005) impact the experience of cognitive fatigue. For some, fatigue serves as a signal to stop performance, whereas others are willing to persevere despite mental exhaustion (Matthews, 2011). Given the impact of fatigue on motivation and ultimately performance, identification of factors that specifically affect older adults' experience of and response to fatigue may be beneficial in understanding and promoting older adults' everyday functioning.

It is possible that there are both personal and situational factors associated with the aging process that are responsible for how an individual older adult responds to fatigue. With respect to personal factors, negative attitudes and beliefs about aging have been shown to be important predictors of functional outcomes (e.g. longevity, disease, injury and cognitive decline; Levy, Slade, Kunkel, & Kasl, 2002; Stroebe, 2000). It is possible that such factors may also influence responses to fatigue. For example, negative beliefs about aging may result in more negative subjective attributions regarding fatigue (e.g., reflects effects of diminished capacity), subsequently affecting both the experience of fatigue and its potential impact on behavior. Similarly, situational factors shown to exacerbate the negative effects of aging on cognitive performance may also be tied to fatigue. For example, something as simple as the time of day in which older adults are tested may influence both subjective and objective aspects of fatigue, perhaps accounting for the disproportionate impact of time of day on performance in later life (West, Murphy, Armilio, Craik, & Stuss, 2000; Martin, Buffington, Welsh-Bohmer, & Brandt, 2008).

Given the potential impact of fatigue on behavior and motivation, and the lack of knowledge regarding the impact of aging, my study will focus on three research questions. First, what is the impact of aging on fatigue, as reflected in performance and psychophysiological factors? Second, how does aging affect the experience of fatigue? And third, how do personal and situational factors that are empirically linked to cognitive performance affect older adults’ responses to fatigue?

Cognitive Fatigue and Aging

Cognitive fatigue is defined in terms of attention and resource depletion (Kanfer & Ackerman, 1989; Hockey, 1993). Models of fatigue propose a limit to the amount of cognitive resources available for any one person to engage (Hockey, 1993). As individuals engage in cognitive activities, they spend their limited resources, reducing the total amount available. Cognitive fatigue is experienced as these resources get low, and serve as a signal to rest. With age, this pool of resources is thought to decrease in capacity, resulting in older adults becoming cognitively fatigued more quickly than younger adults (Kanfer & Ackerman, 1989). This effect may be exacerbated due to older adults also having to expend more effort than younger adults to achieve similar levels of performance (e.g., Hess & Ennis, 2012). In addition, older adults also show slower levels of recovery to baseline following effortful cognitive activity than do younger adults (Steptoe & Marmot, 2005).

Traditionally, cognitive fatigue is induced via executive function tasks and assessed through self-report questionnaires (DeLuca, 2005; Hockey, 2011). Vigilance tasks are considered executive function tasks as they involve the mechanisms needed to resolve cognitive conflict (similar to Stroop or Simon tasks) and are associated with activation of anterior areas of the frontal cortex (Roca, Castro, Lopez-Ramon, & Lupianez et al., 2011). For example, Bunce and Sisa (2002) investigated self-reported fatigue over the course of a demanding, high event rate vigilance task. They found no age differences in vigilance task performance, with younger and older adults being equally able to complete the task. Older adults, however, reported greater amounts of fatigue resulting from the task than younger adults. Deaton and Parasuraman (1993) obtained similar results, with ratings of mental workload exhibiting a disproportionate increase in older relative to younger adults over the course of the given cognitive task. Thus, even when the ability to sustain attention across a task does not change with age, older adults perceive it as more mentally taxing.

Unfortunately, there has been little research examining aging and cognitive fatigue. In addition, the available studies suffer from their reliance on self-report questionnaires. It is possible people are simply not skilled at properly assessing their level of fatigue, or that that different participants respond to fatigue in a different manner. In addition to these usual problems with self-report measures, the existing questionnaires contain insufficient specificity in their definition of fatigue, usually including components of physical fatigue in addition to cognitive fatigue. For example, the frequently used Mental Fatigue Scale (MFS; Johansson, Starmark, Berglund, Rodholm, & Ronnback, 2010) measures noise sensitivity, sleep patterns, and emotionality, including only a single question that assesses cognitive fatigue as is defined by the current study. Given these assessment issues, it is unsurprising that research has failed to demonstrate meaningful associations between subjective reports of fatigue and other measures of fatigue (Bailey, Channon, & Beaumont, 2007; DeLuca, 2005; Krupp & Elkins, 2000).

An alternative means for examining fatigue is through assessment of cardiovascular responses. Systolic blood pressure response (SBP-R; the increase of SBP above baseline) is a relatively direct reflection of sympathetic nervous system response associated with active coping (Obrist, 1981; Wright, Stewart, & Barnett, 2008), and it has been used as an objective index of task engagement. Research with young adults has also suggested that it can be used to assess fatigue (Wright & Gendolla, 2012; Wright, Patrick, Thomas, & Barreto, 2013; Wright & Gendolla, 2012). Fatigue is typically expressed in terms of higher than typical levels of SBP-R during task performance after an extended trial or following previous engagement in a demanding task (for review, see Gendolla, Wright, & Richter, 2012), assuming that the individual perceives performance as both possible and worthwhile. Increases in SBP-R indicate an escalation of the resources required for continued task completion (Smith & Hess, 2014; Wright, Stewart, & Barnett, 2008). The participant must work harder as the task continues to drain his or her resources, increasing fatigue, and thus, SBP-R. Using a resource depletion model (as is common in fatigue literature; Hockey, 2011), there is a theoretical limit to the resources one can engage in a task, resulting in a maximum level of fatigue that can be felt. Once this maximum point is reached, one would expect there to be disengagement from the task--as reflected in decreased SBP-R--under the same conditions (e.g., Stewart, Wright, Hui, & Simmons, 2009). This pattern is predicted by motivational intensity theory (Brehm & Self, 1989): as fatigue levels rise, there is a point at which the task is no longer seen as possible, and disengagement occurs. Thus, SBP-R presents itself as a potentially superior way to assess cognitive fatigue. Unlike the subjective measures, it is not subject to any response bias, as it is linked to sympathetic nervous system functioning (Wright & Gendolla, 2012).

SBP-R has been used by Hess and Ennis (2012) to assess adult age differences in fatigue responses. In this study, older and younger adults engaged in an initial task that was either low or high in cognitive demand, after which they solved a series of multiplication problems for three minutes. Older adults exhibited higher levels of responsivity than younger adults to cognitive engagement, with responsivity increasing with task difficulty. The difficulty of the initial task performed by the participants determined their level of responsivity on the subsequent multiplication task, which is suggestive of fatigue. Those who performed the more difficult task exhibited higher subsequent levels of SBP-R than those who performed the easy version (i.e., greater initial effort expenditure was associated with greater fatigue). In addition, the older adults became significantly more fatigued than the younger adults. This is in part related to the age differences in effort exhibited in the initial task. Related effects were observed by Ennis, Hess, and Smith (2013) and Smith and Hess (2015), who found greater increases in SBP-R over trials in older relative to younger adults. Both sets of studies suggest that aging is associated with increases in fatigue associated with engagement in mentally demanding tasks.

In sum, SBP-R is a measure of task engagement and fatigue that reflects the degree of task difficulty, one's perceived capability to perform the task, and one's motivation to do well. Using a physiological measure such as SBP-R provides the specificity and objectivity lacking in the subjective measures. Using both types of data also allows us to determine what portions of the variability in response to cognitive fatigue is a function of individual differences, or situational characteristics. The subjective measures used in this study are not perfect. They do not fix any of the flaws present in any of the various subjective measures of fatigue. However, by using these subjective measures in addition to objective indices I will be able to compare the two measures. Using both types of measures allows me to test the validity of the subjective measures against the more objective measures.

Situational and Individual Differences in Fatigue

Although fatigue is generally assumed to increase with age, there are personal and situational factors that influence the degree to which fatigue is experienced (Ackerman, 2011). Specifically, the current examines how individual differences in perceptions of cognitive control and situational differences in regard to time of day moderate the effects of cognitive fatigue. Previous research has shown that fatigue is subject to moderation by personal characteristics, such as coping style (Ukueberuwa, & Arnett, 2014), self-efficacy (Findley, Kerns, Weinberg, & Rosenberg, 1998), and psychological distress (Bultmann, Kant, Kasl, Beurskens, & van den Brandt, 2002). These results are typically analyzed under the lens of Expectancy Theory (Carver, Blaney, and Scheier, 1979). Outcome expectancy is the belief that ones effort will result in attainment of desired goals. When outcome expectancy is high, task performance is seen as more important or worthwhile (Gendolla, Wright, & Richter, 2012). When outcome expectancy is low, participants are more likely to see the task as unimportant or not worth their time. Individuals may be more willing to persevere in spite of fatigue if they believe it is worth the effort, have high self-efficacy, or generally perceive the costs of persevering as low. Put simply, performance is best when the task is seen as both possible and worthwhile. For the current study, I am interested in studying individual and situational factors that impact whether or not participants see the task as possible (during a relatively easy cognitive task).

One personal factor that may influence outcome expectancy is perceived control over the task performance (Bielak et al. 2007). Specifically, locus of control refers to individuals' beliefs about the extent to which an outcome is the result of their actions, as opposed to external influences such as other individuals, environmental conditions, or chance (Bielak et al., 2007; Levenson, 1974). If one who believes they are in control of their performance may exert more effort than someone who believes they are not in control. Control beliefs are hypothesized to be especially relevant to older adults (Shulz & Heckhausen, 1999). Aging is associated with changes in goals and motivation (Ebner, Freund, & Baltes, 2006). According to the Selective Optimization with Compensation model, older adults select activities to optimize their best abilities and functions and to compensate for declines and losses (Carstensen, 1992). SET also stresses the impact that motivation plays in older adult cognitive performance, as aging is associated with greater selectivity in when cognitive resources are engaged. This change in goals coincides with a decrease in the belief that one has control over their aging process (Krause & Shaw, 2003). Some older adults believe the decrements associated with aging are preventable, while others believe the declines are inevitable or irreversible. These control beliefs affect a wide range of physical and mental-health outcomes (Rowe & Kahn, 1998). If a task is perceived as outside of ones' control, motivation is likely to be low, especially in older adults, whose goals are already shifting towards maintenance rather than gaining new knowledge (Ebner, Freund, & Baltes, 2006). However, no studies have explicitly studied the relationship between older adult control beliefs and the experience of cognitive fatigue. It is possible that control beliefs are, in part, reflections of the costs of cognitive activity, including fatigue (e.g., greater fatigue leads to reduced beliefs in control). It is also possible, however, that control beliefs reflect attitudes toward aging, which may influence one's perception of self and their subjective responses to fatigue. This latter aspect is a focus in my study. If intellectual control decreases perceived costs, this would make that cost-benefit ratio smaller (i.e., those with higher levels of control would perceive less effort from the task).

In addition, I was interested in examining situational factors that influence older adults' responses to fatigue. One situational factor that has been shown to have a disproportionate impact on older adult cognitive performance is the time of day at which they perform a task. There is a considerable body of literature demonstrating that executive cognitive skills are particularly sensitive to time of day, with both young and older adults showing reduced performance on executive tasks when tested at off-peak time of day (e.g., Intons-Peterson, Rocchi, West, McLellan, & Hackney, 1998; May & Hasher, 1998, West, Murphy, Armilio, Craik, & Stuss, 2000). Regarding aging, it is generally accepted that older adults show a preference for the morning, while younger adults perform better in the afternoon (West, Murphy, Armilio, Craik, & Stuss, 2000). These age trends in time of day preference correspond with the optimal level of performance on cognitive tasks (i.e. older adults perform better in the morning, younger adults better in the afternoon). These patterns in time of day preference mirror the circadian patterns of arousal that are associated with peaks and declines in body temperature, heart rate, and hormone secretion that also change with age (Dijk, Duffy, & Czeisler, 1992).

This effect is especially relevant to older adults, whose performance is significantly more affected by time of day than younger adults, leading to disproportionately greater variability and poorer performance when tested at nonoptimal times (Borella, Caretti, Riboldi, & De Beni, 2010; Hasher & Zacks, 1988; West, Murphy, Armilio, Craik, & Stuss, 2000). Thus, time of day may be an important factor in determining how older adults respond to a cognitively fatiguing situation. When older adults are tested in the morning, they may have more available cognitive resources to deal with a cognitively fatiguing task, and may be more resilient to the effects of fatigue. Older adults who are forced to work later in the day may suffer more effects from a fatiguing vigilance task due to depletion of resources over the morning. A recent study by Iskandar, Murphy, Baird, West, and Armilio et al. (2016) found that Older and younger adults performed differently on verbal fluency tasks depending on the type of day in which they were studied. These time of day patterns tend to be robust when processes involving attentional control. Using both time of day and control beliefs allowed me to examine the factors that moderate both objective and subjective aspects regarding the experience of fatigue.

The Current Study

The goal of my study was to determine whether there are age differences in subjective and objective aspects of cognitive fatigue, and whether cognitive control beliefs and testing situation (i.e., time of day) moderate this experience. To do so, I used the Attention Network Test for Interactions and Vigilance (ANTI-V; Fan et al., 2002) to induce cognitive fatigue. A revised version of the traditional ANT, the ANTI-V allows researchers to more clearly assess each component of the attentional network. The ANTI-V examines three separate processes of the attention network: alerting, orienting, and executive attention. Cognitive fatigue is reflected in the disproportionate slowing of response time over executive attention trials (Holtzer et al., 2011), which tap into the control mechanisms that are thought to be most susceptible to fatigue. For the current study I expected to find results consistent with Holtzer et al.'s work (2011); specifically, as the number of trials (i.e., time on task) increase, response times on the executive attention component on the ANTI-V will also increase more than corresponding response times relating to other task components, indicating cognitive fatigue. This slowing is hypothesized to be greater for older relative to younger adults. This hypothesis is supported by other tasks in which conflict resolution between congruent and incongruent information is tested, such as the Stroop task. The stroop task is often found to be particularly difficult for older adults, as they have disproportionately longer response times on incongruent trials (Gamboz, Zamarian, & Cavallero, 2010). These findings are interpreted as indicating an age-related decline in inhibitory ability for older adults (Bopp & Verhaeghen, 2009). This has further been interpreted as older adults being more susceptible to interference from irrelevant, conflicting information (e.g. Hasher & Zacks, 1988).

Fatigue was measured with both typical subjective assessments of cognitive fatigue and physiological measures. The subjective measures used were the Piper Fatigue Scale-12 (PFS-12) and the NASA-TLX. I used SBP-R as my main physiological measure. I hypothesized that cognitive fatigue—as reflected in increased SBP-R across trials--would be greater in older than younger adults (H1). For SBP-R I had three main hypotheses. First, I expected that SBP-R would be greater for older adults than for younger adults. Second, I hypothesized that SBP-R would increase across trial block. Last, I anticipated that this increase in SBP-R across trial blocks would be greater for older adults than younger adults.

To assess control beliefs, I used the Personality in Intellectual Aging Contexts (PIC; Lachman, 2006). The PIC assesses beliefs and attributions about control over intellectual functioning associated with everyday situations and laboratory tasks. It contains 3 scales: internal control, chance, and powerful others. The scale directly assesses intellectual control, measuring the extent to which individuals believe they are responsible for and able control their behavior and personal outcomes. I hypothesized that control beliefs would moderate older adults' experience of, and response to, fatigue (H2). Specifically, I hypothesized that older adults with high levels of internal control beliefs would respond differently to fatigue compared to those with low levels of internal control beliefs (Control x Quadratic Effect of Trial). There are two primary expected effects. First, internal control beliefs are hypothesized to be negatively related to the experience of fatigue (e.g. those with higher levels of control beliefs will report less fatigue). Second, internal control beliefs will be positively related to task engagement, such that those with high internal control beliefs will exhibit an increased level of SBP-R across all levels of the task.

I expected to find a main effect for time of day (within older adults), such that older adults who were tested in the morning would show better task performance and decreased levels of fatigue compared with older adults who were tested in the afternoon. This would be reflected in a lower level of SBP-R across trials. I also hypothesized that older adults tested in the morning would show a later point of disengagement than older adults who were tested in the afternoon. I expected the subjective measures to follow a pattern similar to the SBP-R results. Participating during their ideal time of day may allow participants to utilize more resources to focus on the task and successfully manage the effects of fatigue.

METHODS

Participants

The sample included 130 participants: 50 younger adults (18 to 20 years of age) and 80 older adults (65 to 81 years of age), and the sample was equally split across genders within each age group. A greater proportion of older adults were tested in order to have sufficient power to examine differences in expectations regarding aging. Older adult participants were community-based volunteers recruited from the NCSU Adult Development Lab's database. Younger adult participants were recruited through the NCSU student subject pool. Initial exclusionary criteria at recruitment was self-reported uncontrolled high blood pressure (i.e., SBP >160 mm Hg or DBP > 100 mm Hg). Thirty-six of the older adult participants reported taking medication for hypertension. Prior to testing, all participants went through an additional screening, with those whose blood pressure was found to be above this criterion not being permitted to participate (one older adult participant was excluded). Participants were assigned to either morning (9am-12pm) or afternoon (1pm-4pm) testing session. Participants were placed in these sessions based on availability. Equal numbers of men and women were tested at each time of day within each age group. To test for a potential confound between time of test with a participants preferred time of day was measured using the morningness-eveningness questionnaire (MEQ; Terman & Terman, 2005). This questionnaire contains 19 questions. Scores can range from 16-86 with scores of 41 or below indicating “evening types”. Scores of 59 or above indicate “morning types”. Scores between 42 and 58 indicate no preference. For younger adults the mean MEQ was 45.5 (*SD* = 8.49; no preference). The range was 37 points, with a minimum score of 28 and a maximum score of 66. For older adults, the mean was 60.4 (SD = 9.79; slight morning preference). The range was 40, with a maximum score of 79 and a minimum score of 39. Thus there is generally support in my sample for older adults preferring the morning to the afternoon. There was a non-significant correlation between time of test (i.e., morning or afternoon) and score on the MEQ, suggesting that there was no confound of time of test with participant preferred time of test $r_{\text{pb}} = -.05$, $p = .536$. Older adult participants were paid $15 for their participation, while younger adults were given class credit. In total, the session took approximately one hour and thirty minutes per participant.

Measures and Equipment

Cardiovascular Responses. The Finometer MIDI (Finapres Medical Systems, Amsterdam, the Netherlands) was used to collect continuous measures of blood pressure and heart rate using a cuff that assesses finger arterial pressure. Pressure readings were obtained with each beat of the heart through the volume-clamp method of Peñáz (1973). Brachial artery systolic and diastolic pressures was extrapolated from finger arterial pressure through the use of waveform-filtering and level-correction methods through the BeatScope software provided with the system. The technology used in the Finometer MIDI has demonstrated reliability and validity (e.g., Gerin, Pieper, & Pickering, 1993; Guelen et al., 2003).

ANTI-V. The Attention Network Test for Interactions and Vigilance evaluates tonic alertness and provides a direct measure of vigilance (Roca, Castro, Lopez-Ramon, & Lupianez, 2011). The ANTI-V is comprised of 8 blocks (64 trials each). The first trial is a practice block with visual feedback, followed by a break, and is not included in the data analysis. The following stimuli were presented in the task: a black fixation cross, a warning tone, a black asterisk, and a row of five cars pointing left or right. The primary goal of the task is to indicate the direction of the middle car by pressing left or right on the keyboards directional arrows. The cars appear on the screen between 400 ms and 1600 ms, so that participants are uncertain as to when a new trial will begin. The duration of the final screen is adjusted so that the total trial time is always 4100 ms. The target cars appear on the screen for 200ms, either above or below the fixation point. A period of 2000ms is allowed for responses.

To analyze the functioning of the executive attention network, the flanker cars pointed in the same direction as the target car (congruent) on half the trials whereas they pointed in the opposite direction (incongruent) in the other half of the trials. To assess functioning of the orienting network, the row of cars was preceded 100ms by a visual cue (an asterisk presented for 50ms), either in the same location as the forthcoming target car (valid), in the opposite location (invalid), or no asterisk was present (no cue condition). To measure the alerting network, a 50 ms warning auditory signal was presented 500 ms before the target car (warning tone) or not (no warning tone). The probabilities of each of these conditions are equal.

The individual component scores (alerting, orienting, and executive attention) were calculated on the basis of two measurements: reaction time (RT) and error rate. For RT—the primary measure of interest—the ratio score of the executive attention is calculated as RT of incongruent condition minus the RT of the congruent condition divided by mean RT for the trials with the executive attention cues. Only mean RT's for correct responses were included in this calculation.

Control Beliefs. Personal control is measured by a combination of three Locus of Control scales derived from the Personality in Intellectual Aging Contexts Inventory short form (Lachman, Baltes, Nesselroade, & Willis, 1982). These scales were modeled after Levenson's (1974) multidimensional locus of control instrument and include Internal, Chance, and Powerful Others. Internal control is assessed by questions such as "it's up to me to keep my mental faculties from deteriorating". The chance scale includes questions such as "I have little control over my mental state". The powerful others subscale includes items such as "I wouldn't be able to figure out postal rates on a package without help". Together, the PIC scales demonstrate good reliability, with alpha coefficients ranging from .76 to .91 (Lachman et al., 1982). Cronbach's alphas were calculated for the subscales in the current study. The internal scale had an alpha coefficient of .87, the chance scale had an alpha of .83, and the powerful others scale had an alpha of .71. I then calculated the reliability for the three subscales, which was found to have a coefficient of .72. Other studies assessing reliability of the PIC Locus of Control Scale yield similar coefficients (Grover & Hertzog, 1991; Soederberg-Miller & Gagne, 2005). Responses were scored on a 6-point Likert-type scale ranging from 1 (strongly agree) to 6 (strongly disagree). Higher scores on the Chance and Powerful Others scales higher scores reflect greater beliefs in the control of external forces on aging outcomes (e.g., negative attitudes towards aging), whereas higher scores on the Internal scale signify stronger beliefs in one's own capabilities (e.g. positive aging attitudes).

Cognitive Ability. In order to provide general assessments of ability, the digit-symbol-substitution and letter-number-sequencing subtests (LNS) from the Wechsler Adult Intelligence Scale, Third edition (WAIS-III; Wechsler, 1997) were used. The LNS consists of 7 blocks, with three trials within each block. In each trial there are both letters and numbers. Participants are read these letters and numbers in a mixed order. The participants are then instructed to say the letters and numbers back to the tester placing the numbers first in ascending order, then the letters in alphabetical order. Participants are given one point for each trial they get correct. Testing was ended early if they missed all three trials within a block. Scores could range from 0 to 21.

The digit-symbol substitution was a timed test, in which participants are given nine digit-symbol pairs followed by a list of digits. Under each digit the subject is instructed to write down the corresponding symbol as quickly as possible. Participants were given two minutes to complete as much of the task as possible.

A verbal Stroop task was also given. The Stroop task was used as it assesses inhibitory functions and involves a similar use of the attention networks as the ANT. The Stroop task consisted of three separate components. First a 72-item sheet of black ink color-words were given to the participants. They had to verbally say the words aloud. After completing this component, they were then given a page with 62 colored blocks. They were instructed to verbally state the color of the blocks. The final trial consisted of items with which there were conflicting color/color-word combinations. In this trial the participants were instructed to say the color of the word, not the word itself. Scores are calculated as the subtracting the average of the non-conflicting trials from the conflicting information trials.

The Vocabulary Test 2 from the Kit of Factor-Referenced Tests (KFRT; Ekstrom, French, Harman, & Derman, 1976) was used to assess verbal ability. This measure contains two five-choice synonym subtests, with each test consisting of 18 items. A total of eight minutes, four minutes per test, is provided for the completion of both halves, and summing the number of correct responses from both subtests generates the total score. Scores could range from 0 to 36.

Subjective Fatigue Ratings. A modified version of the Piper Fatigue Scale-12 (PFS-12) was used to assess subjective feelings of fatigue, both in general and after task administration. While initially designed to assess cancer-related fatigue, it is general enough to be used in other settings (Reeve et al., 2013). It consists of four subscales: behavioral, affective, sensory and cognitive/mood, with three items for each scale. The PFS-12 has high scale reliability with the original 22-item PFS (r= .92) and reliability for the subscales were all above .87 (Reeve et al., 2013). Language in the instructions was altered to make sure that participants were clear that I was interested in cognitive fatigue, and to define the timeframe for fatigue as “currently” rather than “in the past 4 weeks”.

Subjective fatigue was also assessed indirectly using the NASA Task Load Index (TLX; Hart & Staveland, 1988), a well-validated measure of subjective workload. It uses information from six subscales assessing mental demand, physical demand, temporal demand, performance, effort, and frustration to create an overall measure of workload.

Demographic and Health Information. Self-rated physical and mental health was assessed using the SF-36 Health Survey (Ware, 1993). Demographic information was gathered using a 31-item questionnaire that includes questions on age, gender, race, education and income.

Procedure

At the time of their scheduled session, older adult participants arrived at an off-campus testing facility and were given an Informed Consent Form. Younger adults were tested and given their consent form at our on-campus facility. After providing written consent to participate, participants completed the background questionnaire and the SF-36. After completing these initial tasks, participants had their blood pressure screened using a BP-785 automatic monitor (Omron Helath Care, Inc., Kyoto Japan). Next, a finger blood pressure cuff was attached to the index, middle, or ring finger of the participant's non-dominant hand. Cardiovascular baselines were established during the last 5 minutes of 10-minute pretest relaxation period. During this time, participants were asked to sit still, and to not talk or move the arm connected to the blood pressure monitor. This is required to guarantee an accurate baseline measurement. After baseline SBP is established, participants were given the practice trials of the ANTI-V. Once they had experienced the task through this practice, participants were given the PFS-12 and NASA-TLX to measure their self-reported fatigue and workload prior to the task. Cardiovascular responses were measured throughout the remaining 7 blocks of this task. After completing the ANTI-V, participants again completed the PFS-12 and NASA-TLX. Once finished, sensors were detached, and the participants completed the remaining cognitive ability tasks. After all other tasks are completed participants were debriefed and paid.

RESULTS

Participant Characteristics

I first conducted a series of independent sample t-tests on the background variables to identify any differences due to age group. As can be seen in Table 1, the age differences in the cognitive measures were generally in the expected direction, with older adults having higher vocabulary scores and younger adults performing better in the Stroop and Digit Symbol tasks. Unexpectedly, there were no significant age differences found in the Letter Number Sequencing task. Additionally, differences in these variables according to time of day was assessed using independent sample t-tests. Younger adults scored significantly worse on the Stroop in the afternoon (p=.04) than in the morning. No other Time of Day differences were found in the cognitive measures. There were no age or time of day effects for control beliefs. This finding was expected and corresponds with previous research using the PIC (Soederberg-Miller & Gagne, 2005).

Table 1
Demographic Information

Measure	Younger Adults (*N* = 50)				Older Adults (*N* = 80)			
	Morning		Afternoon		Morning		Afternoon	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age	18.81	1.74	19.59	2.11	70.9	5.51	73.90	5.21
Education*	13.21	1.67	13.95	2.21	16.92	1.47	17.32	2.31
Overall PIC Score	-14.99	12.08	-19.16	8.30	-16.57	21.78	-16.02	8.16
Baseline SBP*	113.20	12.08	113.69	18.03	128.26	21.78	126.60	18.73
SF-36 Physical	45.22	3.97	47.96	4.65	47.28	4.42	47.61	4.10
SF-36 Mental*	51.16	6.77	48.70	10.37	56.16	6.82	55.09	8.60
Vocabulary*	17.78	4.09	17.81	3.62	27.35	5.11	27.35	5.13
Digit-Symbol Substitution*	83.09	15.68	82.13	11.18	70.11	12.59	70.11	10.78
Stroop*	10.79	10.07	12.47	3.74	21.11	10.56	21.11	9.42
Letter Number Sequencing	9.88	2.26	9.79	2.43	9.87	2.37	9.87	2.02

*=$p < .05$

Table 2
Subjective Measures of Fatigue

	Younger Adults Time 1		Younger Adults Time 2		Older Adults Time 1		Older Adults Time 2	
Measure	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
TLX Mental Demand*	31.18	25.77	41.80	27.47	51.23	25.52	60.71	28.30
TLX Physical Demand*	8.88	12.15	16.65	16.83	24.90	27.03	46.13	29.98
TLX Temporal Demand*	51.12	25.19	48.61	27.45	63.26	26.76	60.98	23.86
TLX Performance*	13.96	15.37	18.78	13.26	29.25	24.78	30.45	22.99
TLX Effort *	37.78	30.72	43.37	28.62	61.86	27.62	60.95	25.22
TLX Frustration	18.33	17.39	35.00	24.58	25.84	26.06	32.53	26.78
TLX Average*	26.87	16.27	34.03	17.21	42.72	17.47	48.62	18.35
PFS Behavioral	2.69	3.79	6.00	4.85	3.18	4.07	6.96	4.71
PFS Affective	5.53	6.10	9.73	6.22	8.59	5.81	11.333	4.65
PFS Sensory	8.94	5.01	12.90	5.56	8.44	5.66	11.76	5.13
PFS Cognitive	5.86	4.32	9.78	6.40	6.24	5.61	9.28	5.79
PFS-12 Average	5.76	3.89	9.60	4.74	6.61	4.60	9.83	4.19

*$p < .05$ for both age and time effects

Subjective Perceptions of Workload and Fatigue

The next set of analyses focused on self-reported changes in workload and fatigue using 2 x 2 x 2 (Age Group X Time of Day [AM vs PM] X Time of Test [Pre- vs Post-test]) repeated-measures multivariate analyses of variance (MANOVA). Mean scores for the subjective ratings can be seen in Table 2. Ratings from the six TLX subscales were used as the dependent variable in the initial MANOVA (Table 3). Significant multivariate main effects were found for age group, time of day, and time of test. Most importantly, a significant interaction between age group and time of test was observed.

Table3

Results for MANOVA on TLX Scores

Effect	$F(6,117)$	p	$\eta_{partial}^2$
Time of Day	2.61	.021	0.12
Age Group	8.83	<.001	0.31
Time of Test	14.86	<.001	0.43
Time of Day x Age	0.65	.694	0.03
Time of Day x Time of Test	1.61	.149	0.08
Age x Time of Test	3.69	.002	0.16
Age x Time of Day x Time of Test	1.63	.144	0.08

As hypothesized, subsequent univariate analyses revealed older adults provided higher ratings than younger adults for all subscales except frustration ($p <$ .004). Mental demand, $F(1,125) = 20.69$, $p < .001$, $\eta_{partial}^2 = .14$ physical demand, *F*(1,125) = 47.99, $p<.001$, $\eta_{partial}^2=.28$, and frustration scores, *F*(1,125)=37.381, $p<.001$, $\eta_{partial}^2=.23$, also increased from pre to post test. This increase in mental demand was important, as it was hypothesized to have a strong relationship with fatigue. It is interesting to note there were no significant increases in self-reported effort from pre to post-test.

Significant time of day effects were found for mental demand, *F*(1, 125) = 7.59, $p = .007$, $\eta_{partial}^2=.06$, temporal demand, *F*(1, 125) =14.10, $p<.001$, $\eta_{partial}^2=.10$, effort, *F*(1, 125) =4.07, $p=.05$, $\eta_{partial}^2=.03$, and frustration, *F*(1, 125) =5.47, $p=.021$, $\eta_{partial}^2<.00$, with scores being higher for those tested in the afternoon than for those tested in the morning. I did not find the expected disproportionate increase in workload for older adults in the afternoon, with younger adults reporting similar increases to the old in workload in the afternoon.

As for the interaction of age and time of test, this was only significant for physical demand, *F*(1,125)=10.31, $p=.002$, $\eta_{partial}^2=.08$, and frustration, *F*(1,125) = 6.878, $p = .01$, $\eta_{partial}^2=.05$. Older adults had a disproportionately larger increase in their self-reported physical demand (*M*pre = 24.90, *SD* = 25.52; *M*post = 46.12, *SD* = 29.98) than did the younger adults (*M*pre = 8.91, *SD* =12.16; *M*post = 16.68, *SD* = 16.82). In contrast, the interaction for the frustration scale was driven by a disproportionate increase in scores reported by younger adults (*M*pre = 18.35, *SD* = 17.39; *M*post =35.08, *SD* = 24.59) relative to the older adults (*M*pre=25.84, *SD*= 26.06; *M*post =32.53, *SD* = 26.77). Older adults reported greater levels of frustration prior to the start of the first trial, but did not increase by the same magnitude as the younger adults over the course of the task.

I next conducted a repeated measures MANOVA using scores from the four PFS-12 subscales (Table 4). As expected, there was a significant main effect for age group and time of test. There were no other significant main effects or interactions (*ps* > .19). Results of the univariate analyses indicated there were significant ($p <$ .001) increases in all subscale scores from pretest to posttest. A significant main effect for age was only found for the affective subscale (p =.012), with younger adults reporting less affective fatigue (M = 7.64) than older adults (M= 9.96.). These results were somewhat surprising as it was expected that older adults would report greater levels of fatigue across all the subscales, not only the affective subscale.

Table4

Results from MANOVA on PFS-12 Scores

Effect	$F(1,123)$	p	η_{partial}^2
Time of Day	1.743	.145	.054
Age Group	4.48	.002	.128
Time of Test	30.44	<.001	.5
Time of Day x Age	0.61	.660	.02
Time of Day x Time of Test	1.05	.387	.03
Age x Time of Test	1.34	.261	.04
Age x Time of Day x Time of Test	1.82	.130	.06

Overall, the TLX performed more consistently with expectations than the PFS-12. Importantly, participants reported increases in fatigue and workload due to time of test. Older adults reported perceptions consistent with greater levels of fatigue. There was only minimal evidence for disproportionate increases in subjective reports over time and at non-preferred times of day.

Control Beliefs. Next, I ran a GLM-based repeated-measures ANOVA with control beliefs included as an additional between-participant factor in order to examine potential moderating effects of this factor on subjective perceptions of fatigue and workload. A composite score was created using a procedure common in the literature (e.g., Kennedy, Allaire, Gamaldo, & Whitfield, 2012; Lachman, 2006; Marsiske & Willis, 1995) in which the three PIC subscales were first converted into T-scores, then the chance and powerful others subscales were reverse coded and combined with the internal subscale by taking the mean of the three subscales. High scores indicate high levels of internal control beliefs.

I did not make any a priori hypotheses on how time of day and control may interact. However, during the course of the study it became clear that control beliefs could moderate the effect of time of day. I expected that those with high levels of internal control would show less fatigue effects at all times of day than those with low levels of internal control beliefs.

I then conducted two Time of Test x Time of Day x Control Beliefs repeated-measures ANOVAS, one for each subjective measure (TLX and PFS-12). Only data from the older adults were used in this analysis. For the TLX, there was a significant main effect for time of day $F(1,73) = 4.819$, $p = .031$, $\eta_{\text{partial}}^2 = .062$ and a significant Time of Test x Control Belief interaction, $F(1,73) = 20.87$, $p < .001$, $\eta_{\text{partial}}^2 = .222$. Older adults reported greater levels of workload when tested in the afternoon. To decompose the Time of Test x Control Belief interaction, high and low internal control belief estimates were created by calculating scores at plus or minus one standard deviation from the mean PIC scores. New repeated measures ANOVAS were run with these estimated scores as covariates. This analysis revealed that individuals with high levels of internal control beliefs reported overall higher levels of workload and increased more in their reported workload over time. When the PFS-12 was used as the dependent variable, no significant effects for control beliefs were found (p = .19). In total, feelings of control seem tied to the amount of workload reported on the test, although in a different direction than initially hypothesized. I had expected that high levels of control would indeed make a person try harder on the task, but I also expected that because they were trying harder, the task would seem easier, and they would report that it required less workload. Instead, high levels of control directly lead to higher perceptions of workload.

ANTI-V Task Performance

Multilevel modeling (MLM) was used to examine the impact of trial block (i.e., task length), time of day, and age group on ANTI-V task performance. I first focused on accuracy scores. These scores were analyzed for outliers and one older adult participant was removed for having disproportionately low accuracy throughout the task. Next, I used a fully unconditional null model to analyze the Intraclass Correlation Coefficient (ICC). Results of this model indicated that 60% of the variance in accuracy is between-subjects, while 40% of the variance in accuracy was within-subjects. Accuracy was then examined using the following model to assess the impact of both the linear and quadratic components of trial block (Level 1 variables), age group, and time of day (the Level 2 variables), along with within- and cross-level interactions. (Note that the quadratic effect was included in this and all subsequent analyses involving trial block, but was dropped from the models if no significant effects involving it were obtained.)

$$\text{ANTI-V}_{it}(\text{Accuracy}) = \beta0_{it} + \beta1_{it}\,(\text{Trial Block}) + \beta2_{it}\,(\text{Trial Block} * \text{Trial Block}) + r_{it}$$
$$\beta_{0i} = \gamma_{00} + \gamma_{01}(\text{Age Group}) + \gamma_{02}(\text{Time of Day}) + \gamma_{03}\,(\text{Age Group} * \text{Time of Day}) + U_{0i}$$
$$\beta_{1i} = \gamma_{10} + \gamma_{11}(\text{Age Group}) + \gamma_{12}(\text{Time of Day}) + \gamma_{13}\,(\text{Age Group} * \text{Time of Day})$$
$$\beta_{2i} = \gamma_{20} + \gamma_{21}(\text{Age Group}) + \gamma_{22}(\text{Time of Day}) + \gamma_{23}\,(\text{Age Group} * \text{Time of Day})$$

Age group is coded so that younger adults are the reference group. Time of day is coded such that morning is the reference group. Trial block has been transformed in this and all subsequent models such that the first trial block is the reference group (i.e., trial block 1 = 0). Results are displayed below in Figure 1.

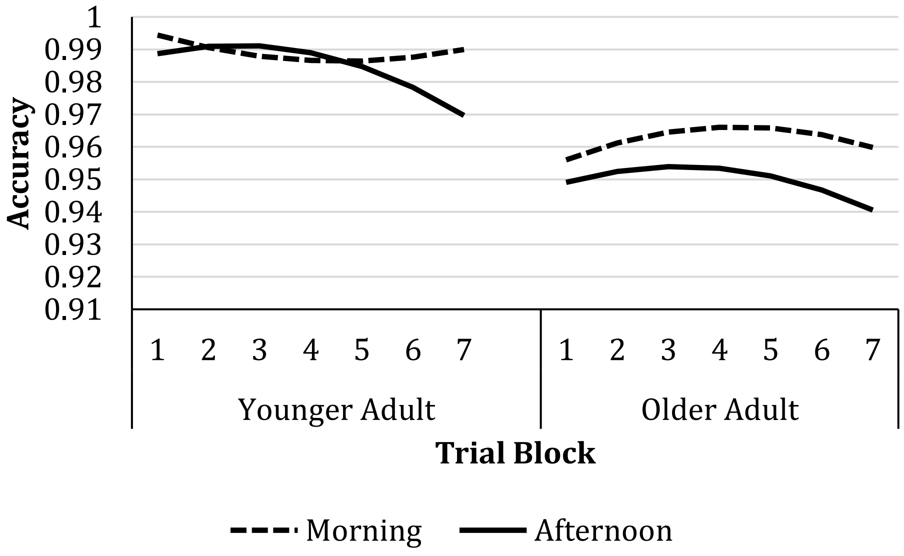

Figure 1. ANTI-V task accuracy estimates by age group, time of day, and trial block

Results indicated a significant main effect for age group, *b* = -.038, *t*(122)=-4.515, *p*<.001, along with significant interactions between age and trial block, *b* = .011, *t*(755)=-2.19, *p*=.029, age and the quadratic effect of trial block, *b* = -.002, *t*(767)=-1.99, *p*=.047, and time of day and the quadratic effect of trial block, *b* = -.001, *t*(755)=-1.99, *p*=.047. The lack of any linear or quadratic changes in trial block for the younger adults indicated that these effects were specific to the older adults. Older adults were becoming less accurate as trial block increased. The Trial Block x Time of Day interaction was decomposed by altering the reference group for Time of Day. In the morning there were no significant linear or quadratic effects for trial block. In the afternoon there was a marginally significant effect for quadratic trial block only (*p* = .076). It was only when the reference group was made to be the 7th trial that there were marginally significant differences found for Time of Day, *b* = -.02, *t*(755)=-1.96, *p*=.052. In total, these data suggest that performance was worse in the afternoon than in the morning in the last trial block of the task.

As hypothesized, younger adults performed better in the task than older adults. It should be noted, however, that task accuracy was generally high in both groups: 98% for the younger adults and 95% for the older adults. This model accounted for 2.4% of the level 1 (within-person) variance in ANTI-V accuracy, and 13.3% of the variance at level two (between-person).

Executive Attention Scores. Next, I constructed a similar model, substituting executive attention difference scores—the main variable of interest—as the dependent variable in the model. Executive attention scores were calculated by subtracting mean response times (RT) for congruent trials from those for incongruent trials within each trial block. The resulting score is a measure of how much participants were affected when incongruent cues were present in the trial. Given that older adults preformed significantly worse than young adults throughout the task, mean-centered accuracy was included as a Level 1 covariate. The model is as follows:

ANTI-V_{it}(Executive Attention)= β_{0it} + β_{1it} (Trial Block) + β_{2it} (Trial * Trial) + β_{3it}(Accuracy)
$\beta_{0i} = \gamma_{00} + \gamma_{01}$(Age Group) + γ_{02}(Time of Day) + γ_{03} (Age Group * Time of Day)
$\beta_{1i} = \gamma_{10} + \gamma_{11}$(Age Group) + γ_{12}(Time of Day) + γ_{13} (Age Group * Time of Day)
$\beta_{2i} = \gamma_{20} + \gamma_{21}$(Age Group) + γ_{22}(Time of Day) + γ_{23} (Age Group * Time of Day)
$\beta_{3i} = \gamma_{30} + \gamma_{31}$(Age Group) + γ_{32}(Time of Day) + γ_{33} (Age Group * Time of Day)

Prior to performing this analysis, the data were analyzed for the presence of outliers (only RT for correct trials was used for further analysis). If a RT on an individual trial was two standard deviations below or above the mean time for a trial block, it was removed from further analysis. This resulted in elimination of 1.1 % of the trials in the old and 0.7% in the young. After removing the outliers, executive attention scores were calculated for each trial block. As an initial step, fully unconditional null models were again used to calculate the ICC. Results indicated that 17% of the variance associated with these scores is between-person and 83% of the variance is within-person. There were no significant main effects or interactions associated with the quadratic trial block component, and thus it was removed and the model was rerun. This new model revealed significant main effects for age group and trial block as well as a significant Age Group x Trial Block interaction (Table 5).

Table 5

Analysis of ANTI-V Executive Attention Scores: Results of Basic Multilevel Model

Fixed Effects	Estimate	DF	SE	*p*
Intercept	194.32	122	40.29	<.001
Exec Attention ACC	645.09	122	29.41	0.012
Age Group	107.45	122	51.52	0.041
Trial Block	23.08	754	9.11	0.011
Time of Day	72.54	122	57.51	0.209
Age Group x Trial Block	-25.44	754	11.61	0.028
Age Group x Time of Day	-33.69	122	73.35	0.646
Trial Block x Time of Day	-16.03	754	13.02	0.217
Age Group x Trial x Time of Day	11.57	754	16.58	0.483

Results from this model explain 1.2% of the within-person variance, and 1.0% of the between-person variance of Executive Attention scores. The results of this model are depicted in Figure 2. The significant main effect for trial block indicates that the executive attention scores of younger adults were increasing across trial blocks. When the reference group was made the older adults, no significant main effect emerged. Younger adults performed overall better on the ANTI-V task, but slowed across trials, suggestive of fatigue. Inconsistent with expectations, the performance of older adults did not deteriorate over time

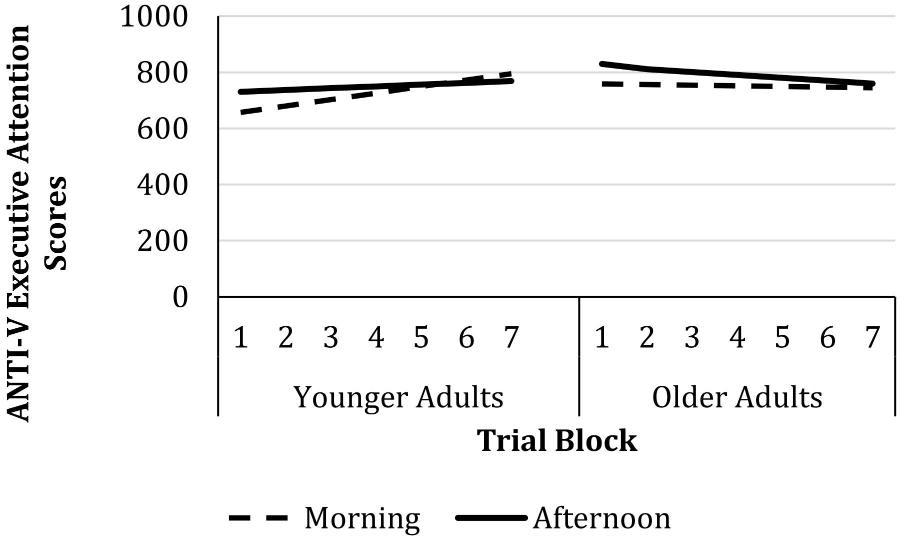

Figure 2: Estimated executive attention scores by age group, time of day, and trial block

Effect of Trial Type. I next examined performance associated with each of the other components of the ANTI-V task: alerting and orienting. This was done using the same model as before. For alerting scores—calculated as the difference between trials on which there was no tone present versus those on which there was—I had hypothesized that participants would improve over the course of the task. However, there were no significant main effects or interactions in this model. Consistent with expectations, there were no significant main effects or interactions present in the model involving orienting scores (calculated by subtracting scores tone trials from no tone trials; *ps* < .60). These results indicate that, as expected, only the executive attention component of the ANTI-V task was associated with any evidence of fatigue.

Control Beliefs. In the next set of analyses, I examined how older adults' executive attention scores were affected by their control beliefs. A new ICC was calculated for the older adult group, indicating that 18.4% of the variability in executive attention scores is between individuals whereas 81.6% of the variance is within-individuals. The following model was used to examine the impact of trial block (both linear and quadratic components) as Level 1 variables and control beliefs and time of day as Level 2 variables. The data were coded such that morning was the reference group for time of day. Control beliefs were grand-mean centered in this, and all subsequent models in which it is present.

ANTI-V_{it}(Executive Attention)= β_{0it} + β_{1it} (Trial Block) + β_{2it} (Trial Block * Trial Block) + β_{3it} (Accuracy)+ rit
β_{0i} = $\boldsymbol{\gamma}_{00}$ + $\boldsymbol{\gamma}_{01}$(Control Beliefs) + $\boldsymbol{\gamma}_{02}$ (Time of Day) + $\boldsymbol{\gamma}_{23}$ (Control Beliefs * Time of Day)+ U0i
β_{1i} = $\boldsymbol{\gamma}_{10}$ + $\boldsymbol{\gamma}_{11}$(Control Beliefs) + $\boldsymbol{\gamma}_{12}$ (Time of Day) + $\boldsymbol{\gamma}_{23}$ (Control Beliefs * Time of Day)
β2i = $\boldsymbol{\gamma}_{20}$ + $\boldsymbol{\gamma}_{21}$(Control Beliefs) + $\boldsymbol{\gamma}_{22}$ (Time of Day) + $\boldsymbol{\gamma}_{23}$ (Control Beliefs * Time of Day)

There were no significant effects found for the quadratic effect of trial block, ($p >$ .08), so it was dropped from the model and the data were reanalyzed with only the linear effect. The results of this analysis are presented in Table 6 and are depicted in Figure 3. There was a significant main effect for control beliefs, as well as significant Trial Block x Control Beliefs and Trial Block x Control Beliefs x Time of Day interactions. In order to graph these effects, high and low internal control belief groups were created by estimating scores at plus or minus one standard deviation from the mean PIC scores. This model accounted for 2.2 % of the within-person variance in older adults ANTI-V scores, and 5.9% of the between-subject variance.

Table 6

Analysis of Older Adults' ANTI-V Executive Attention Scores with Control Beliefs in the Model

Effect	Estimate	DF	SE	*p*
Intercept	301.07	73	35.45	<.001
Exec Attention ACC	212.00	73	47.38	0.503
Trial Block	-2.81	471	7.81	0.717
Control Beliefs	12.25	73	4.35	0.003
Time of Day	61.22	73	50.29	0.213
Trial Block x Time of Day	-7.91	471	.96	0.478
Trial Block x Control Beliefs	-2.95	471	11.12	0.002
Time of Day x Control Beliefs	-11.38	73	6.20	0.058
Trial Block x Time of Day x Control Beliefs	2.74	471	1.37	0.044

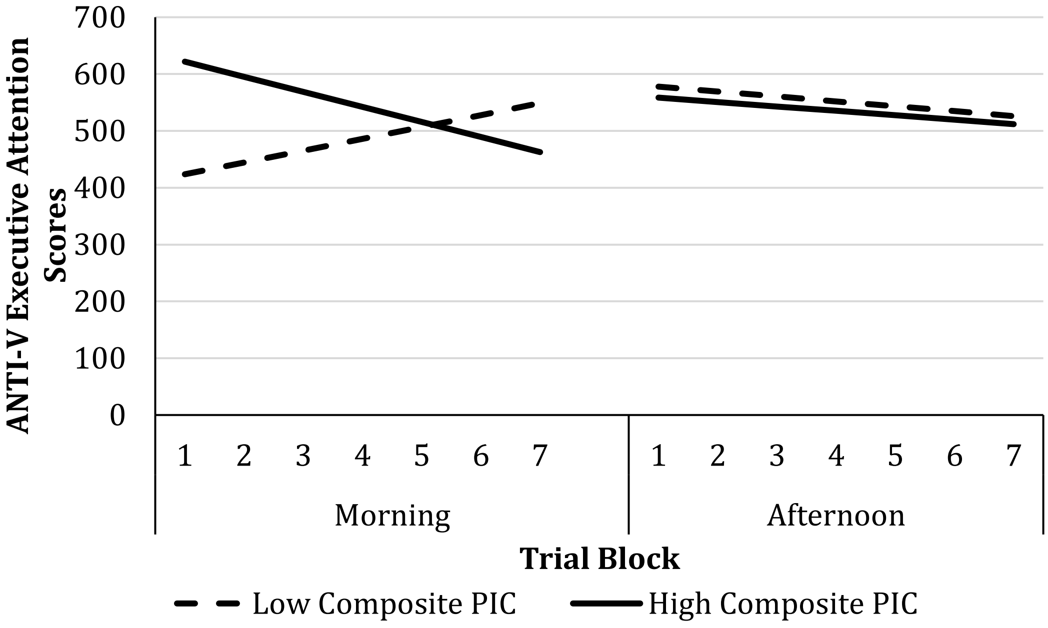

Figure 3: Estimated ANTI-V executive attention scores for older adults as a function of control beliefs, time of day, and trial block.

When the reference group for time of day was altered to be the afternoon, no significant effects were observed. This indicates that the significant interaction present in the model for control beliefs was driven by performance differences in the older adults who were tested in the morning. Additionally, a main effect for trial block only occurred when low control beliefs were used as the reference group, indicating that the performance of the low control group got worse over time. Somewhat unexpectedly, those with low control beliefs performed better than those with high beliefs on the first three trial blocks of the task, with differences disappearing thereafter.

Relationship with Subjective Fatigue. I next examined the relationship between the subjective measures of fatigue and ANTI-V performance. I first calculated TLX change scores by standardizing the ratings for each scale, and then calculated the mean of the six scale scores at each time of test as a composite index of workload. I then subtracted the pretest from the post-test scores to obtain a measure of change in subjective workload as a proxy for fatigue. Higher scores indicate greater change in perceived workload, suggestive of an increase in fatigue. These scores were then added to the following model:

$$\text{ANTI-V}_{it}(\text{RT}) = \beta0_{it} + \beta1_{it}\ (\text{Trial Block}) + \beta2_{it}\ (\text{TLX Change}) + \beta3_{it}(\text{Accuracy}) + r_{it}$$
$$\beta_{0i} = \boldsymbol{\gamma}_{00} + \boldsymbol{\gamma}_{01}(\text{Age Group}) + \boldsymbol{\gamma}_{02}(\text{Time of Day}) + \boldsymbol{\gamma}_{03}\ (\text{Age Group * Time of Day})$$
$$\beta_{1i} = \boldsymbol{\gamma}_{10} + \boldsymbol{\gamma}_{11}(\text{Age Group}) + \boldsymbol{\gamma}_{12}(\text{Time of Day}) + \boldsymbol{\gamma}_{13}\ (\text{Age Group * Time of Day})$$
$$\beta_{2}i = \boldsymbol{\gamma}_{20} + \boldsymbol{\gamma}_{21}(\text{Age Group}) + \boldsymbol{\gamma}_{22}(\text{Time of Day}) + \boldsymbol{\gamma}_{23}\ (\text{Age Group * Time of Day})$$

There were no significant effects related to TLX change in the model (*ps* < 0.5; Table 7).

Table 7

Results of Mulitlevel Model Examining ANTI-V Executive Attention Scores as a Function of TLX Change

Effect	Estimate	DF	SE	*p*
Intercept	235.63	124	450.31	0.892
Accuracy	471.82	124	455.41	0.680
Age Group	96.94	124	38.31	0.044
Trial Block	14.51	765	6.52	0.037
TLX Change	-35.37	124	58.38	0.551
Age x Trial Block	-21.03	765	8.29	0.023
Age x TLX Change	127.92	124	80.0	0.073
Trial x TLX Change	9.42	765	13.2	0.475
Age x Trial x TLX Change	-31.91	765	18.11	0.055

Next, I examined the relationship between the PFS-12 and ANTI-V executive attention scores. Prior to this analysis, I created PFS-12 composite scores according to the scoring manual provided with the survey: responses were simply added together and divided by the total number of items. Change scores were then calculated by subtracting the pre-test scores from the post-test scores. TLX composite scores were created by adding together each of the subscales (reverse coding performance) and dividing by the number of subscales. I then substituted these scores for composite TLX change scores in the just-described models. Once again, however, there were no significant main effects or interactions (Table 8). Together, these results suggest little relationship between executive attention performance and subjective indices of fatigue and workload.

Table 8

Results of Mulitlevel Model Examining ANTI-V Executive Attention Scores as a Function of PFS Change

Effect	Estimate	DF	*SE*	*p*
Intercept	182.43	124	452.35	.687
Accuracy	81.50	765	457.70	.859
Age Group	40.25	124	45.49	.378
Trial Block	10.52	765	8.11	.195
PFS Change	-4.33	124	5.41	.425
Age x Trial Block	-13.99	765	9.99	.162
Age x PFS Change	9.99	124	6.73	.140
Trial x PFS Change	0.89	765	1.23	.472
Age x Trial x PFS Change	-1.33	765	1.53	.384

Executive Attention Summary. As hypothesized, older adults had worse performance than younger adults on the executive attention component of the ANTI-V. Additionally, older adults did perform slightly worse in the afternoon. Although control beliefs did have an effect on ANTI-V performance, it was not in the hypothesized direction. In the morning, older adults with high levels of internal control performed worse on the initial trials of the task. Interestingly, they improved over trials. Only the low control participants (tested in the morning) showed signs of fatigue. In the afternoon, where control beliefs were hypothesized to have the largest effect, no differences were found.

Systolic Blood Pressure Responses

For each participant, baseline SBP was calculated by taking the mean over the last five min of the baseline period. I then obtained SBP response (SBP-R) scores by subtracting baseline response from the mean response during each trial block of the ANTI-V task. The means of each trial block were calculated after correcting for any irregularities in the data. Irregularities were determined to be any values greater than 2+/- standard deviations from the mean, and these data were subsequently removed from further consideration. In each analysis, the baseline CV response (grand mean centered) was entered as a covariate to control for the possibility that the magnitude of response was associated with the baseline. Fully unconditional null models were used to estimate the ICC. For SBP-R, 83.9 percent of variance was between persons and 16.1 percent was within person. The full model is as follows:

$\text{SBP-R}_{it} = \beta 0_{it} + \beta 1_{it}\,(\text{Trial Block}) + \beta 2_{it}\,(\text{Trial Block} * \text{Trial Block}) + r_{it}$

$\beta_{0i} = \boldsymbol{\gamma}_{00} + \boldsymbol{\gamma}_{01}(\text{Age Group}) + \boldsymbol{\gamma}_{02}(\text{Time of Day}) + \boldsymbol{\gamma}_{03}\,(\text{Age Group} * \text{Time of Day}) + \boldsymbol{\gamma}_{04}\,(\text{Baseline SBP})$

$\beta_{1i} = \boldsymbol{\gamma}_{10} + \boldsymbol{\gamma}_{11}(\text{Age Group}) + \boldsymbol{\gamma}_{12}(\text{Time of Day}) + \boldsymbol{\gamma}_{13}\,(\text{Age Group} * \text{Time of Day}) + \boldsymbol{\gamma}_{14}\,(\text{Baseline SBP})$

$\beta_{2i} = \boldsymbol{\gamma}_{20} + \boldsymbol{\gamma}_{21}(\text{Age Group}) + \boldsymbol{\gamma}_{22}(\text{Time of Day}) + \boldsymbol{\gamma}_{23}\,(\text{Age Group} * \text{Time of Day}) + \boldsymbol{\gamma}_{24}\,(\text{Baseline SBP})$

No significant effects associated with the quadratic component of trial block were obtained (*ps* > .18), and thus I removed these effects from the model. Under this model, there was a significant main effect for age group, a significant Age Group x Trial Block interaction, and a significant Age Group x Trial Block x Time of Day interaction (see Table 9). The absence of main effects for trial block and time of day when the young group is used as the referent suggests that these effects are being driven by the older adults. In order to decompose this interaction, I made older adults the referent group, and systematically altered the referent group for time of day to make comparisons. Only when the morning was the referent group did older adults significantly change (decrease) across trials, b=-.67, t(771)=-.526, p<.001.

Table 9

Analysis of SBP-R: Basic Multilevel Model

Effect	Estimate	DF	SE	*P*
Intercept	23.19	122	5.43	<.001
Base Systolic	-.014	122	0.04	.019
Age Group	9.11	122	2.54	<.001
Trial Block	0.15	765	0.16	0.369
Time of Day	0.32	122	2.73	0.909
Age Group x Time of Day	-3.56	122	0.21	0.312
Age Group x Trial Block	-0.82	765	3.48	<.001
Time of Day x Trial Block	-0.15	765	0.23	0.515
Age Group x Trial Block x Time of Day	0.59	765	0.30	0.035

In sum, when older adults were tested in the morning, where they were hypothesized to be at their peak, they did not show the effects of fatigue and instead exhibited decreases in reponsivity over the course of the task (See Figure 4). This model accounted for 3.3% of the within-person variance and 15.7% of the between-person variance present in SBP-R.

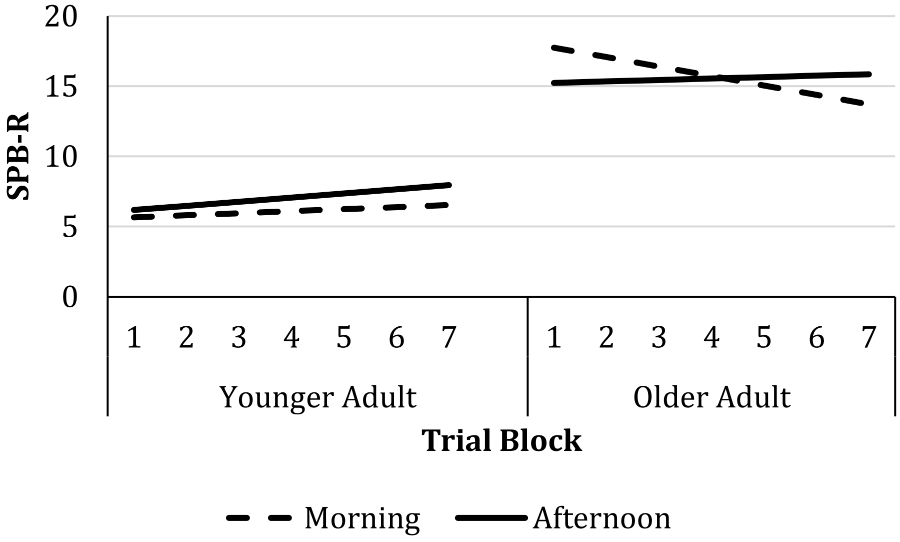

Figure 4: SBP-R estimates by age group, trial block, time of day

Control Beliefs. In order to examine the hypothesis that fatigue—as reflected in change in SBP-R—in older adults would be moderated by control beliefs, I examined SBP-R with PIC scores as a Level 2 predictor using the following model:

$\text{SBP-R}_{it} = \beta 0_{it} + \beta 1_{it}\,(\text{Trial Block}) + \beta 2_{it}\,(\text{Trial Block * Trial Block}) + r_{it}$
$\beta_{0i} = \boldsymbol{\gamma}_{00} + \boldsymbol{\gamma}_{01}(\text{Control Beliefs}) + \boldsymbol{\gamma}_{02}\,(\text{Time of Day}) + \boldsymbol{\gamma}_{23}\,(\text{Control Beliefs * Time of Day}) + \boldsymbol{\gamma}_{04}\,(\text{Baseline SBP})$
$\beta_{1i} = \boldsymbol{\gamma}_{10} + \boldsymbol{\gamma}_{11}(\text{Control Beliefs}) + \boldsymbol{\gamma}_{12}\,(\text{Time of Day}) + \boldsymbol{\gamma}_{13}\,(\text{Control Beliefs * Time of Day}) + \boldsymbol{\gamma}_{14}\,(\text{Baseline SBP})$
$\beta_{2i} = \boldsymbol{\gamma}_{20} + \boldsymbol{\gamma}_{21}(\text{Control Beliefs}) + \boldsymbol{\gamma}_{22}\,(\text{Time of Day}) + \boldsymbol{\gamma}_{23}\,(\text{Control Beliefs * Time of Day}) + \boldsymbol{\gamma}_{24}\,(\text{Baseline SBP})$

Full results can be seen in Table 10. As hypothesized, there was a main effect for both the linear and quadratic components of trial block. There were also several significant two-way interactions along with a significant three-way interaction between trial block, control beliefs, and time of day. These results are depicted in

Figure 5. This model accounted for 22.6% of the between subjects variance and 10.4% of the with-subjects variance in SBP-R.

Table 10

Analysis of SBP-R as a function of Control Beliefs, Trial Block, and Time of Day

Effect	Estimate	DF	SE	*p*
Intercept	20.01	73	7.95	<.001
Base Systolic	-0.20	73	0.06	<.001
Trial Block	-2.71	467	0.47	<.001
Control Beliefs	-0.09	73	0.22	0.59
Time of Day	-4.28	73	2.49	0.10
Quadratic Trial Block	0.34	467	0.07	<.001
Trial Block x Time of Day	1.68	467	0.67	0.011
Trial Block x Control Beliefs	0.05	467	0.06	0.369
Control Beliefs x Time of Day	0.72	73	0.31	0.018
Trial Block x Control Beliefs x Time of Day	-0.30	467	0.08	<.001
Quadratic Trial Block x Control Beliefs	0.002	467	0.009	0.820
Quadratic Trial Block x Time of Day	-0.19	467	0.11	0.066
Quadratic Trial Block x Control Beliefs x Time of Day	0.02	467	0.01	0.114

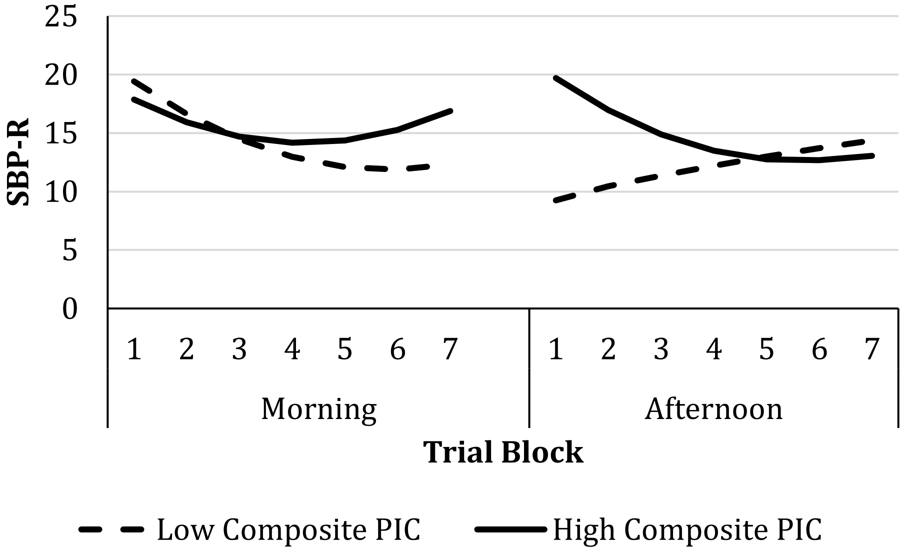

Figure 5. Estimates of older adults' SBP-R by time of day, control beliefs, and trial block.

The lack of a main effect for control beliefs in this initial model indicates that there were no significant differences between the two control belief groups in the morning. There was a marginally significant main effect for control beliefs (*p* = .10) suggesting that older adults with high levels of internal control beliefs gave slightly more effort in the morning. Regardless of control beliefs, participants decreased in SBP-R across trials, a pattern of responding inconsistent with fatigue. When tested in the afternoon, significant linear, *b*=-3.16, *t*(458)=-4.80, *p*<.001, and quadratic effects, *b*=.34, *t*(458)=3.19, *p*=.002, due to trial block were observed in those with high control beliefs. Those with low levels of control beliefs significantly increased across quadratic trial block (*b*=.18, *t*(458)=-2.30, *p* = .025). This result indicates that participants with low levels of internal control beliefs showed the hypothesized fatigue effects. In the afternoon, the difference between the high and the low control belief groups was only significant when tested with trial block 1 as the referent (*p* = .067 at trial block two). This suggests that although control beliefs may have had some initial effect on SBP-R (in the afternoon), those differences disappeared as the trials progressed.

These findings suggest that older adults show differential SBP-R based on the time of day in which they are tested and their control beliefs. When tested in the morning, regardless of control beliefs, older adults' SBP-R decreased throughout the task. In the afternoon, those with high levels of internal control beliefs utilized more resources at the start of the task when compared to those with low internal control beliefs. This difference quickly dissipated across Trial Blocks. Again, those with high levels of control beliefs did not show the expected pattern for fatigue effects.

Relationship with Subjective Fatigue. I next examined subjective workload effects using the previously described basic MLM analysis, including TLX change scores as an independent variable in the model. Full results of the MLM procedure are in Table 11. Two significant three-way interactions were found (Age Group x Trial Block x Time of Day; Age Group x Trial Block x TLX Change). The lack of any significant main effects for TLX Change in this initial model indicates that younger adults were not driving this effect. When the reference group was changed to be older adults, a significant Trial Block x TLX Change interaction became significant (*p*= .01), such that older adults who reported higher levels of workload had increased levels of SBP-R across the task. This is a critical finding as it supports that SBP-R as a measure sensitive to increases in perceived workload, and illustrates a connection between self-reported workload and patterns of effort and fatigue in the task. Changes in workload seem to correspond well to energy mobilization in older adults, which may be reflective of a response to fatigue. When PFS-12 scores were included in the model, no significant main effects or interactions were found involving this measure ($p > .10$).

Table 11

Analysis of SBP-R as a Function of TLX Change Scores

Effect	Estimate	DF	*SE*	*p*
Intercept	23.41	118	5.53	0.006
Base Systolic	-0.19	118	0.05	<.001
Age Group	12.80	118	2.59	<.001
Trial Block	0.18	761	0.16	0.261
Time of Day	0.37	118	2.76	0.894
TLX Change	-2.21	118	3.96	0.580
Age Group x Trial Block	-0.81	761	0.21	<.001
Age Group x Time of Day	-3.08	118	3.53	0.385
Age Group x TLX Change	4.34	118	5.40	0.417
Trial Block x Time of Day	-0.18	761	0.23	0.420
Trial Block x TLX Change	-0.41	761	0.33	0.211
Time of Day x TLX Change	3.30	118	5.67	0.563
Trial Block x Time of Day x TLX Change	-0.22	761	0.47	0.628
Age Group x Time of Day x TLX Change	-1.68	118	7.75	0.828
Age Group x Trial Block x TLX Change	1.18	761	0.45	0.008
Age Group x Trial Block x Time of Day	0.62	761	0.29	0.031
Age Group x Trial Block x Time of Day x TLX Change	-1.08	761	0.64	0.085

Systolic Blood Pressure Summary

Overall, my results were in line with expectations. Older adults showed an overall greater amount of SBP-R than younger adults. This indicates that, as found in previous studies, older adults have to use more mental resources to complete the same tasks as younger adults. Time of Day showed some of the hypothesized effects, with older adults initially showing more willingness to exert effort in the morning, and no signs of fatigue. In contrast, those older adults tested in the afternoon expended less initial effort, and did not wane over the course of the task. Time of day of testing had little effect on younger adults.

Finally, control beliefs did impact older adult effort and fatigue throughout the task. When participants reported having high levels of control beliefs they had higher levels of SBP-R, indicative of giving more effort. In addition, participants seemed aware of this increased effort. Participants' increases in SBP-R corresponded with an increase in reported workload. This was especially true for older adults tested in the afternoon. Although the benefits of these control beliefs seemed to disappear quickly over the course of this task. However, it was only those tested in the afternoon, with low control beliefs that were found to significantly increase over time, in a way that is indicative of fatigue.

DISCUSSION

I designed this study to examine age differences in subjective and objective assessments of cognitive fatigue. I hypothesized that executive attention scores, SBP-R, and subjective fatigue scores would be: (a) greater in older than younger adults, (b) increase over time, and (c) increase disproportionately over time for older adults. I also examined the extent to which time of day and individual differences in control beliefs moderated these effects as well as the relationship between objective and subjective indices of fatigue.

Cognitive Fatigue

In this study I assessed fatigue using four different measures: ANTI-V executive attention scores, SPB-R, and the two subjective measures (TLX and PFS-12). Across all measures, when general patterns of performance were examined (i.e., not including time of day and control), evidence was inconsistent with respect to both the identification of fatigue and the hypothesized age effects. Participants did not exhibit a pattern of ANTI-V performance that was consistent with my hypotheses. I had hypothesized that both younger and older adults would become more impacted by the incongruent cues over time, increasing their executive attention scores. Only the younger adults showed this pattern. Older adults displayed the opposite pattern, becoming less impacted by the incongruent condition as the task progressed. This is inconsistent with previous literature using the ANTI-V such as the work of Holtzer et al., (2011). In the current study we showed little general evidence for cognitive fatigue defined in terms of ANTI-V executive attention scores. Older adults successfully maintained a vigil without feeling the effects of fatigue.

Analysis of the SBP-R data revealed a similar pattern of results. Younger adults showed the hypothesized increase in SBP-R over time suggestive of fatigue. Older adults showed a decrease across trial block, however, indicating that they used less effort as the task progressed. This result is inconsistent with not only my hypotheses but also previous research that shows older adults typically exhibit a disproportionate increase in SBP-R over time in a cognitively demanding task (Hess & Ennis, 2013; Smith & Hess, 2015).

For the two subjective measures, older adults reported higher levels of workload and fatigue than younger adults, and both scores increased over the course of the task. However, the TLX was the only measure for which the expected age differences in fatigue effects were obtained. Specifically, older adults did indicate a greater increase in workload than did the younger adults, but this increase was specifically tied to perceptions of physical demands. Although previous literature has shown that TLX increases physical demand, typically there are at least marginal demands for several of the subscales (Bunce and Sisa, 2002). Previous literature using the TLX and vigilance tasks has reported a similar increase in physical demands (Bunce & Sisa, 2002). However, there were no age differences in change over the course of the task on the other TLX scales—including those assessing effort and mental demands—nor on the other index of subjective fatigue (i.e., PFS12).

In total, I did not find the hypothesized fatigue effects. Although the ANTI-V has been reported to be a reliable and valid measure of fatigue (Roca, Castro, Lopez-Ramon, & Lupianez, 2011), there are other studies that have found inconsistent results (Gamboz, Zamarian, & Cavallero, 2010; Jennings, Dagenbach, Engle, & Funke, 2007). In these studies, once processing speed was taken into account, differences between their age groups on the executive attention component disappeared. This is consistent with other attention network studies that find cognitive fatigue is strongest for those who exhibit declines in processing speed (Holtzer et al., 2012).

One possible explanation for my inability to find significant fatigue effects may be that I had a relatively select sample of high functioning older adult participants. This current study had older adults who, on average, had 17 years of education. In Holtzer et al., (2012) the average number of years of education was 14. Their older adults were on average 80.6 years old, almost 10 years older than the average age for older adults in my sample. It is possible that my sample was too young, and too highly educated to show similar fatigue effects as Holtzer et al. (2012). Vigilance tasks such as the ANTI-V assess the functioning of anterior areas of the frontal cortex (Roca, Castro, Lopez-Ramon, & Lupianez et al., 2011). If my sample was younger and more educated, they may not have had sufficient declines in their frontal areas to show fatigue as measured by the ANTI-V (West, 1996). I tested whether inclusion of our other cognitive measures as a covariate in the models affected executive attention scores, but this inclusion did not result in any significant cognitive ability effects and did not alter any previously reported effects. Thus, even the older adults who performed worse on the cognitive measures were not experiencing cognitive fatigue. In sum, the ANTI-V failed to produce cognitive fatigue, which may have negatively impacted my ability to identify fatigue effects in my other measures. This failure to produce fatigue effects may be due in part to my highly educated sample of older adults. As suggested in the next section, however, it may be that fatigue effects will be more likely under certain conditions than others.

In other words, it may be important to consider other moderating factors besides age.

Moderators of Fatigue

In this study, I was also interested in whether there were situational and personal factors that would moderate the level of fatigue felt by the participants. Specifically I examined how the time of day in which you test an individual and their control beliefs impact their responses on a lengthy vigilance task.

Time of Day. I expected older and younger adults to perform differently in the morning and afternoon due to the circadian fluctuations in cognitive alertness that change with age (Hasher et al., 1999; Anderson, Campbell, Amer, Grady & Hasher, 2014). As expected, older adults reported greater levels of workload (higher TLX) in the afternoon in relation to the morning. This self-reported workload did not translate into differential performance on the ANTI-V or higher levels of SBP-R in the afternoon. Thus, older did not have better overall performance when tested in the morning compared to the afternoon. This finding is inconsistent with an abundance of literature that suggests older adults perform better on cognitive tasks when tested in the morning compared to the afternoon (Schmidt et al., 2007; Hasher, Zacks & May, 1999).

A possible explanation for the lack of consistency between my results and those reported elsewhere is that I had a unique sample regarding preferred time of day. Many studies have used the MEQ to show the skew towards morningness for older adults and eveningness among younger adults (May et al., 2005; Intons-Peterson et al., 1998; Monk & Kupfer, 2007). In this study, however, we had 51 participants report an "intermediate" score for the MEQ. Almost half of this sample indicated no preference for a particular time of day, with similar numbers of older (n = 24) and younger adults (n = 27) reporting no preference. Those at the more extreme ends of the scale did fall into the expected age preferences, with mostly older adults preferring the morning and mostly younger adults preferring the evening. However, the fact that almost half the sample reported no preference for time of day may be the cause for the lack of strong time of day effects.

Control Beliefs. I hypothesized that older adults who believed they were in control of their performance would report being less fatigued by the ANTI-V than those who believed external factors were responsible for their performance. I expected that this self-reported lower level of fatigue would be reflected in less fatigue as measured by the objective measures. These hypotheses were not supported. Older adults with higher levels of internal control beliefs self-reported greater workload over the course of the task compared to older adults with lower levels of internal control beliefs. However, this increase in self-reported fatigue did not result in increases in fatigue as measured by the ANTI-V or SBPR.

On the ANTI-V, older adults who had greater levels of internal control beliefs were more slowed—at least initially—by the incongruence of trials than were those with lower levels of internal control. This is contrary to previous literature suggesting that perceived control leads to better cognitive performance in older adults across a variety of tasks (e.g., Neupert & Allaire, 2012, Soederberg & Lachman, 1999; Satori, Wadley, Clay, Parisi, Rebok, & Crowe, 2012). Despite this increased impact of the incongruent trials, those with high levels of control improved over time. This is a pattern of responding that suggests they were not fatigued by the task despite their increased subjective reporting of workload.

Analysis of the SBP-R data revealed a similar pattern to the ANTI-V data. Those with high levels of internal control beliefs exhibited higher levels of engagement (higher SBP-R) during the initial trials of the task, suggestive of greater effort exertion (when compared to those with low levels of internal control). Interestingly, level of effort decreased in these same individuals as the task progressed. As with the ANTI-V data, this suggests that those with high control beliefs did not feel greater levels of fatigue than those with low control beliefs. This is despite their worse performance and higher levels of effort expenditure.

High internal control beliefs were associated with increases in SBP-R, but worse executive attention performance—at least initially. One possible explanation for this pattern of performance is that the ANTI-V is not a task in which it is beneficial to use more effort. Explicit monitoring theory proposes that increasing effort can prompt individuals to attend to their performance in a manner that disrupts execution (Yu, 2015). Under this theory, greater effort leads to an increased monitoring of explicit processes. This increased monitoring shifts one from relying on their automatic processes to more controlled processes (Yu, 2015; Montero, 2015). For tasks that require automatic functioning, switching to using controlled process disrupts task performance (Yu, 2015). In the ANTI-V, older adults with high levels of internal control beliefs may have focused more on the task and given more effort. However, this increased effort may have required the participants to rely on their slower controlled processes, which in turn translated into higher executive attention scores. The fact that other aspects of performance, such as accuracy, did not suffer suggests that the slowing and high engagement exhibited by high control participants may reflect a difference in approach to task when compared to those with low control beliefs. These findings point to a general concern relating to the use of systolic blood pressure. Interpretation of SBP-R depends highly on the context of the task. High levels of SBP-R could mean greater memory load, greater anxiety, or use of more controlled processes. Thus, the same level of SBP-R—while still indicative of processing demands—may reflect different processes depending on under which circumstances it is observed (e.g., early versus late in a task).

Interactions Between Time of Day and Control Beliefs

I made no *a priori* hypothesis regarding the interaction of time of day and control beliefs. The results of my analyses, however, revealed several instances in which the effect of control beliefs depended on the time of day. For the ANTI-V, differences between the control belief categories were only evident when tested in the morning. In the morning, those with high control beliefs had worse performance on the ANTI-V compared to those with low levels internal control beliefs. This result possibly indicates it was only in the morning that older adults had the cognitive resources to switch to using controlled rather than automatic processing. This supports previous research showing that older adults have more resources available to use on cognitive tasks when tested in the morning.

Across all times of day, it was only ever those with low control beliefs who had patterns of responding (in the ANTI-V and SBP-R) that were indicative of fatigue. According to the SBP-R data, it was only during the afternoon that those with low control beliefs were fatigued by the task. The ANTI-V data suggests that low control belief participants only exhibited fatigue-like patterns of performance when tested in the morning. Thus, although my two objective measures provided evidence of fatigue, they provided me with contradictory results in regards to which scenarios produce cognitive fatigue. The ANTI-V data suggests older adults with low control are fatigued when tested in the morning. The SBP-R data suggests that older adults with low control beliefs are only fatigued when tested in the afternoon.

Conclusions

The results of this study support the finding that aging is associated with an increased self-reported experience of fatigue (Avlund, 2013). More importantly, when older adult participants reported increased workload on the task they had corresponding increases in their SBP-R compared to those older adults who did not report greater workload. This suggests that older adults who found the ANTI-V more taxing, had a greater physiological response. In future studies it will be important to determine the direction of this relationship. Do people perceive the task as more difficult, and then respond physiologically? Or, do peoples physiological responses lead them to perceive the task as more difficult?

The present study also demonstrates the importance of assessing personal and situational variables when measuring cognitive fatigue in healthy older adult participants. I found that age, by itself, was not a useful indicator of who experienced greater levels of fatigue. Only when time of day and control beliefs were included in the models that objective indicators of fatigue became significant. Low levels of internal control beliefs may be a risk factor for experiencing greater levels of cognitive fatigue in healthy older adult populations.

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