THESIS

THE RHYTHM OF COGNITION: OLDER ADULTHOOD EDITION

Submitted by

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In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Spring 2024

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ABSTRACT

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Circadian rhythm is a delicate function that regulates multiple processes, such as cognition, sleep, and appetite. As humans age, their circadian rhythms shift to become earlier, resulting in their cognitive peak performance being earlier in the day. This study's main goals were to investigate if older adults (N = 139; M_{age} = 69.22; range = 60-89) who completed online cognitive tasks over 7 days at peak hours performed better than those who completed them at off-peak hours, as well as to determine if there were specific cognitive tasks that older adults did better on during these peak times. Four cognitive tasks were used to measure working memory, inductive reasoning, episodic memory, and processing speed. As tested by Repeated Measures Analysis of Variance (RMANOVA), results showed no significant between-group differences, which indicated that the different test timing groups did not differ in their cognitive performance. The RMANOVA results also revealed no significant effects of test timing groups for any of the individual cognitive tasks. These findings are inconsistent with the little research available regarding on- and off-peak test timing in older adults and suggest the need for a more well-controlled study focused on older adults. If a more reliable on-peak test time for older participants is identified, then clinicians who test cognition could have the ability to detect cognitive decline earlier on. Ultimately, this could lead to earlier diagnoses or recognition of abnormal changes in cognition.

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OVERVIEW

The 2019 United States census estimates showed that the country's 65-and-older population has multiplied in the last 10 years due to the aging Baby Boomer generation (U.S. Census Bureau, 2020). In the past decade, this population has grown by over 30% or 13 million people (Jordan, 2020). As people age, they undergo many changes in biological processes, including a shift to earlier circadian rhythm (CR) timing (Yoon et al., 2003). Past studies that compared older adults to their younger counterparts have shown the impact of CR timing on cognition. Older adults typically show higher cognitive ability in earlier hours compared to evening hours (Wilks et al., 2021). Understanding normal changes in a person's cognition and CR as they age has the possibility to help clinicians and researchers pinpoint earlier abnormal changes. This will also allow us to determine best practices for older adults in scheduling their important daily activities around the times they perform at their cognitive peak.

Circadian Rhythm (CR)

There are multiple influences on a person's body as they prepare to fall asleep and wake up. Each person has internal circadian clocks that follow a 24-hour repetitive cycle called the CR (NIH, 2020). The circadian clock is located within the brain and other vital organs that sync with the environment. This clock is attributable to environmental processes like day and night and is responsible for feelings of sleepiness and wakefulness. The alignment of the circadian cycle and sleep timing is essential for the quality and duration of sleep people receive (Duffy et al., 2015). There are a variety of CRs that impact biological performance in humans. These include sleep-wake cycles, glucose uptake cycles, hormone regulation, and body temperature changes. Examining the variations in sleep-wake, glucose, and hormone cycles, and body temperature

changes could lead to a better understanding of how CR affects a person's physical and mental performance. These fluctuations in the CR could explain why cognitive performance is better at some times of day versus others (Hasher et al., 2005). CR affects cognitive function through arousal, which is needed for effortful cognitive tasks such as executive functioning skills (Xu et al., 2021). Within a typical day, a person's cognitive and physical performance is exposed to peaks and valleys synchronized with the CR (Pica et al., 2013). The optimal time within a person's 24-hour cycle is assessed by their biological features like body temperature, hormones, and heart rate. This reflects the peak times of a person's circadian cycle, where their mental resources are at their highest (Pica et al., 2013). Cognition declines with age, so optimizing older adults' cognition within their circadian peak performance windows is of great importance. Thus, the following sections summarize the literature about how age impacts CR and cognition.

Young Adults

Much of the research surrounding CR and its effects on cognitive performance has focused on young adults between 18 and 34 years or comparing young adults to their older counterparts. Studies on how CR influences cognitive functions have some variation in findings. However, they generally trend toward younger participants having their best performances in both attention and working memory tasks in the afternoon and their worst performances in the early morning (Xu et al., 2021).

Even within younger adulthood, there are peak circadian times for performance. Research has found that people are generally either morning or evening types, while few report being neutral or "neither" (Hornik & Tal, 2009). Some people are natural early risers, while some stay up late at night (NIH, 2022). Many studies (e.g., Horne & Ostberg, 1976; 1977; Kerkhof, 1985) have tried to determine what makes a person a morning or evening type or why people have

different CR. Chronotype (morningness/eveningness) is based on interindividual differences related to mental health, self-reported sleep, and gender (Kjorstad et al., 2022). There are multiple ways to determine if a person is a morning or evening type and determining when they will show a peak in performance. Morning types have a significantly earlier peak arousal time than evening-type people, and they have been shown to have higher core-body temperatures during the day, with lower evening temperatures. Evening types show higher core temperatures later in the day and evening with lower morning temperatures. Meanwhile, neutral or "neither type" people show temperatures and arousal that are in between the two. Researchers have used the Horne-Ostberg Morningness-Eveningness Questionnaire (MEQ) (Horne & Ostberg, 1976) to help categorize people into morning, neutral, or evening types. Many articles suggest that 90% of younger adults are categorized as neutral or evening types (Ngo et al., 2018).

In experiments with solely young adults, participants performed the most consistently and showed the highest scores on early evening cognitive tests when compared to earlier in the day (Hornik & Tal, 2010). These findings demonstrate how an individual's CR influences cognition. Young adults show lower cognitive performance when tested at off-peak (i.e., morning) times of the day (Ngo et al., 2018). Research shows that testing during peak circadian arousal enhances cognitive performance in immediate and delayed recall (Hornik & Tal, 2010). Ngo and colleagues (2018) found that when younger adults were tested at peak versus nonpeak times of day, nonpeak groups typically showed reduced attention regulation, higher distractibility, and lower scores on word recall memory tasks.

Fatigue effects and CR changes contribute to time-of-day effects on memory (Leirer et al., 1994). Both can explain why younger adults show their best performance in both attention and working memory in the afternoon and their worst performance in the early morning (Xu et

al, 2021). In more intensive studies that involved changing a young adult's CR, there were findings that demonstrated that inhibitory control and attention were moderated specifically by circadian control (Burke et al., 2015). The authors held participants in an environment free of time cues for 73 days, where they underwent two 28-hour forced desynchrony protocol segments, including 18 hours of wake time in dim light followed by 9 hours of scheduled sleep-in darkness. Burke and colleagues (2015) did this to separate the effects of sleep homeostatic and circadian processes on reaction time, sustained visual attention, working and delayed recall, and cognitive speed. The findings showed that circadian timing influence was observed for almost all the measures they examined. They found that participants had their worst performances 1-2 hours after their new habitual wake time, which could simulate early morning testing in young adults. However, overall performance incrementally improved over the first 4 hours of scheduled wake times (Burke et al., 2015). This meant that younger participants needed a period of wakefulness before being at peak performance. The evidence demonstrates that for younger adults, late afternoon/evening is best for cognitive performance, according to their CR.

CR Changes with Age

Despite some CR patterns in young adulthood, the CR is a delicate process that can change based on multiple factors. One factor that may contribute to CR timing change is the aging process. Starting in older adulthood, around age 60, CR shifts earlier. This change is known as phase advance, and it results in older adults performing cognitive tasks better earlier in the morning and poorer in the evening**.** Older adults often go to bed earlier and wake up earlier than younger adults (Yoon et al., 2003). According to their internal circadian clocks measured by body temperature and hormone levels, older adults' (ages 60-65) peak sleep time is between 7 and 8 p.m., with wake hours between 3 and 4 a.m., versus young adults (ages 21-32) who do

better with a bedtime between 11 p.m. and 12 a.m. and a wake-up time around 8 a.m. (Cooke & Ancoli-Israel, 2011). In the past, researchers assumed there was one optimal time of day that differentiated a person's performance regardless of other confounds, such as age (e.g., Baddeley et al., 1970; Blake, 1967). However, other research has contradicted this. Hasher et al. (2005) surveyed 210 undergraduate students and 91 older adults and found that 94% of 18–22-year-olds self-reported as evening types and 75% of 66–78-year-olds self-reported as morning types. There appears to be a significant shift in rhythm patterns from young adulthood to older adulthood. (Hasher et al., 2005). There are quite a few components of the circadian system that change with age, affecting awakening times and altering sleep. These issues include the deterioration of the internal clock, signal transmitters becoming less sensitive, the induction of daytime sleepiness, and other aging issues (Edgar, 1994). However, almost no research examines how this changes as adults age, especially interindividual differences based on age among older adults.

Optimal Hours for Older Adults 60+

A regular sleep timing change is noticed in older adults, where they begin to go to bed earlier and wake up earlier than their younger counterparts (Duffy et al., 2015; Li et al., 2018). Sleep studies in older adults have reflected that this group tends to receive and "need" a significantly smaller amount of sleep than younger adults (Yoon et al., 2003). However, older adults display increased daytime sleepiness, resulting from this less sleep at night, which could reflect their lower later-day cognitive performance and their need to go to bed earlier (Kroeger & Vetrivelan, 2023). Wilks and colleagues (2021) stated that there is a measurable shift from evening type to morning type with increased age. To my knowledge, there are no longitudinal lifespan studies that track how gradual or abrupt this shift in type is or when it begins. Typically, older adults follow a pattern of higher cognitive arousal and performance in the morning

compared to the evening. Research has shown that circadian fluctuations throughout the day impact cognitive alertness. Anderson and colleagues (2014) tested older participants at an optimal time of day (defined as 8 a.m.) and compared their cognitive test performance to younger adults who were tested at 3 p.m. They found that the neural patterns and arousal activity of older adults in the morning were like that of the younger adults tested in the afternoon (Anderson et al., 2014). In the same vein, a study of inhibitory control performed on older adults by Manly and colleagues (2002) found significantly higher error rates later in the day compared to those tested at optimal morning times. This research points to the morning as optimal hours for cognitive task completion among older adults.

Impact of CR on Cognition Amongst Older Adults

It is important to note that even in healthy aging, there is a slight decline in cognitive abilities with advanced age. However, the impact of CR on cognition is still apparent, with older adults typically having better cognition in earlier hours compared to evening hours (Wilks et al., 2021). The research published thus far is conflicting regarding whether older adults' variance in performance between their on-and off-peak times is as significant as that found in their younger counterparts. Rothen and Meier (2017) found that when given a prospective memory task, younger adults performed measurably better in their on-peak rather than off-peak times. However, there was no significant difference observed in older adults. Documenting the effects of aging on cognition, younger adults reliably surpassed their older counterparts for every cognitive task. In a study performed by Wilks and colleagues (2021), older adults completed four cognitive tests per day via a smartphone over seven days that tested associative memory, processing speed, and visual working memory. They found significantly worse performance on the associative and visual memory tasks in the evening than in the morning. Parallel to this were

reports of low mood and high fatigue levels during evening testing hours (Wilks et al., 2021). Pica and colleagues (2013) argued that executive functioning is directly connected to the CR and fluctuates based on what resources a person has available. This results in changes in the inhibitory control and retrieval-induced forgetting processes. Researchers have found that when examining simulated medication and appointment adherence over 13 days, prospective memory was better in older adults in the morning, followed by a midday decline and a late-day plateau (Leirer et al., 1994). When older adults are tested in the morning, there are regions of the brain that are active during cognitive tests that are not active during those same tests in the afternoon (Anderson et al. 2014). Also, older adults tested at the optimal time of day are more likely to resist distraction (Anderson et al., 2014). Most studies confirm an age-related difference in CR and its relation to cognition between younger and older adults, but further study is needed in older adults. Specifically, there is a need to study the changes within older adults from young-old to old-old to understand the relationship between CR and cognition in older adulthood, as interindividual differences remain untested.

Present Study

The present study aimed to examine the associations between time of day and cognitive performance among older adults. The present study is one of the first to test older adults' CR across older adulthood. This allows for an examination of changes within the cognitive aging process and interindividual differences within the older adult population. This study will add to the minimal amount of current literature surrounding CR changes and cognition, evaluating the differences in the link between cognition and CR based on age within older adulthood.

The associations were tested between CR and cognitive performance in older adults aged 60 years of age and older. Participants performed four cognitive tests every day for seven days:

backward digit span, word recognition, letter series completion, and object match. Participants were analyzed in three groups: those who generally took their tests in the morning, those who generally took their tests in the evening, and those who did both (i.e., participants were free to choose when they completed the tasks each day). A fluctuating group offers an intriguing opportunity to explore if there is a gradient within CR with relation to cognition. If CR has an impact, results within the fluctuating group are expected to be between the on- and off- peak groups. Average cognitive scores were used to evaluate if a group showed significant differences based on the time of day they completed the cognitive tests. I also looked at the interaction between the age of the participant and time group to evaluate if increased age moderates CR effects on general cognition (i.e., with greater older age, are the CR effects greater?). Additionally, each cognitive task was evaluated separately to determine if group differences in time-of-day performance varied by cognitive domain. The between subjects' interaction effect between age and the test timing group of each cognitive task was also analyzed individually.

Research Questions

1a. During a 7-day study, do older adults who complete cognitive tests at optimal hours (i.e., morning) perform better than those who complete them at off-peak hours (i.e., evening) and/or those who fluctuated in the times they chose to take the test?

I hypothesized that the older adults who performed their cognitive tasks earlier in the day or during specific on-peak hours would perform the highest. Next, the group who did some tests in the morning and some in the evening would have the second highest average score, and the lowest score would be with the older adults who completed their cognitive tasks in the evening or nonpeak hours.

1b. Is there an interaction between age and test timing?

I hypothesized that there would be an interaction effect between age and test timing, whereby increased age is associated with a greater likelihood of exhibiting more pronounced effects of CR on general cognitive scores.

2a. During a 7-day study, are there particular cognitive tasks (involving inductive reasoning, processing speed, working memory, and episodic memory) where older adults exhibit better performance during on-peak (morning) hours compared to off-peak (evening) hours or fluctuating (some morning, some evening)?

I hypothesized that I would see group differences; however, I was uncertain which measures specifically in the cognitive domain would be the most vulnerable to CR. As mentioned previously in the literature, the neural patterns and arousal activity (which influence processing speed) of older adults in the morning were like those of the younger adults tested in the afternoon (Anderson et al., 2014). The literature describes that a morning person's processing speed will be the first to decline as the day progresses since their neural networks begin to fire earlier than others (Anderson et al., 2014). This means that as the day goes on, the slower this function becomes. However, some literature has shown that visual and associative memory tests are the most sensitive to CR and phenotype in older adults (Wilks et al., 2021). Even in healthy aging brains, one of the first cognitive changes is slowing in attention and multitasking, both of which are attributed to working memory (Howieson, 2015). Some research has shown that historical and autobiographical memories, which are examples of episodic memory are relatively stable as humans age; however, the accuracy and detail of the memory is what begins to decline (Murman, 2015). Because no one has examined how CR affects a wide range of cognitive abilities in older adults, I predicted variation by cognitive domain but not a specific effect.

2b. Is there a difference within age on specific cognitive tasks when performing at on-peak, off-peak, or fluctuating times?

There is no research that determines a difference within older age on specific cognitive tasks based on CR. However, if I base my knowledge around typical aging patterns, then I believe that the older a person becomes, the more their cognitive skills would decrease, especially if they were within the off-peak test timing group. I expected that this typical cognitive decline with age would have presented a more dramatic effect on specific cognitive tasks. However, I was unsure which measures would show the greatest age x CR interaction.

METHODS

Participants

The current data were taken from a larger study focused on the variability in daily activity and cognitive performance (Bielak et al., 2019). The original sample contained 207 community-dwelling adults aged 60.02 - 91.66 years (*M* = 70.45; 62 men, 145 women; 98% Caucasian) residing in Northern Colorado. Participants were recruited through both electronic and published advertisements given to local senior centers and societies. To be a part of the study, participants had to be able to see and hear well with assistance, be fluent in English, have never been diagnosed with dementia or mental illness, and not identify as full-time caregivers. All participants scored at least a 26 on the Mini-Mental State Examination (MMSE; Folstein et al., 1975), demonstrating competent general cognitive ability. Participants without access to a computer or the internet (*n* = 59) and those who did not perform the daily online surveys (*n* = 2) were excluded from the current study because they could not complete the daily online portion of cognitive tests. An additional 10 participants were excluded due to missing three or more days of cognitive tasks. Those missing data from two or fewer days were included (*n* = 9). Those with missing data had their weekly mean for that specific cognitive task inputted into the missing data point. The final sample for the study (see Table 1) was 139 participants aged 60.02 - 89.63 years (*M* = 69.22; 41 men, 98 women). Those involved in the study were highly educated (*M* = 17.75 years; *SD* = 5.95), self-assessed to have few health conditions (*M* = 2.26; *SD* = 1.76) and limited depressive symptoms (*M* = 6.12; *SD* = 5.28), and self-reported to have excellent or very good health (68.27%).

Table 1
Time Group Descriptive Statistics

		N	Minimum	Maximum	*M*	*SD*
Fluctuating	Age		61.50	85.13	69.60	6.19
N = 31	Years Education		12	24	17.87	3.23
	Males	13				
	Females	18				
On-Peak	Age		61.98	84.46	70.77	5.57
N = 32	Years Education		13	24	17.66	2.75
	Males	12				
	Females	20				
Off-Peak	Age		60.02	89.63	68.41	5.98
N = 76	Years Education		12	32	17.75	3.44
	Males	16				
	Females	60				

Procedure

Colorado State University's institutional review board approved the study protocol. Prospective participants were screened during a telephone interview or through email communication. Those eligible to participate underwent a 2-hour one-on-one health, cognition, and activity assessment at the local senior center. They completed daily activity surveys and cognitive tests on the survey website every day for the next week (Week 1). The following week, participants were asked to complete a separate written activity diary every day for a week (this data will not be shown in the present analyses) (Week 2). Half of the participants completed the online daily activity assessments and cognitive tasks the first week, while the other half completed the written daily diaries their first week. Then, the groups switched tasks for their second week. This was done to counterbalance the groups and control for order effects by randomizing who went into each week group to minimize bias. Each participant spent about 2.5 – 3 weeks in the study, and each participant received a phone call or email to remind them of the first day of their online survey and then again halfway through the week. Participants were

incentivized with monetary compensation, with the amount dependent on the number of days the tasks were completed throughout each week. Additionally, those who completed every day of the tasks were entered into a drawing for a monetary bonus. Participants were asked to continue with the surveys even if a day was missed in between.

The current study was part of a larger project; only procedures relevant to the current study will be discussed. The study used the times of day each adult completed the cognitive tasks. The survey website only allowed access to the tasks once every 24 hours. However, it could be completed at any time of day. Participants were asked to detail the prior day's activity, so they were encouraged to complete the survey each evening or the next morning to avoid forgetting. Each day, participants completed all four cognitive tasks, an activity questionnaire (not reported in this paper), and three brief questionnaires (not reported in this paper). The entirety of the online survey took about 20 minutes to complete. Overall, participants finished an average of 6.70 out of 7 days (SD = 1.03) of the daily survey and cognitive tests. Data was collected over 17 months.

Measures

Test Timing

This current investigation used information collected from past studies to define on-peak and off-peak times of day (Anderson et al., 2014). In this study, three groups were created: on-peak, off-peak, and fluctuating. I defined on-peak hours as between 4 a.m. and 11:45 a.m. and off-peak hours anytime from 11:46 a.m.to 3:59 a.m. To qualify for grouping, a participant had to complete a minimum of five of their survey days within one of the time periods (e.g., five days of cognitive tasks between 4 a.m. and 11:45 a.m. qualified an "on-peak" participant). If they completed half of their days in one time period and half in the other (e.g., three days of cognitive

tasks between the hours of 4 a.m. and 11:45 a.m. and four days between 11:46 a.m. and 3:59 a.m.), they were put into the fluctuating group (see Table 1).

Cognitive measures

Each of the following measures was given every day for 7 days.

Word recognition. Participants were shown a series of 16 individual words in the middle of a computer screen for 8 consecutive seconds and were asked to memorize the list. Following the first list, the participants were given a distraction task that lasted 8 seconds and then exposed to a second list with the original 16 words woven within it. Instructions noted to the participants that as they went through the list, if they had seen the word before, they should press the "*z*" key and the "*l*" key if the word was new. Each word was one syllable that contained between three and five letters. Higher scores meant greater word recognition and the goal of this measure was to test episodic memory by counting the total number of correctly recalled words.

Backward digit span. The participants were shown a sequence of numbers on the screen. After the series, the participants were asked to enter the digits they saw in inverse order. The number series varied between three and eight digits, and each participant was given two trials of each length. This task measured working memory and the longest accurate period that was exactly recalled in both trials was used as the outcome measure.

Letter series completion. Participants were given letter strings that followed a specific pattern, and they were asked to enter what the following letter in the pattern would be. Participants would not see all the available word strings, as it was determined by how many items they could get through in the time provided. This task measured inductive reasoning and the percentage of letter strings that the participant correctly answered in 6 minutes was used in this study.

Object match. Participants were shown two pairs of unnamed objects and asked to decide as quickly as possible if the pairs matched or not. If they matched, participants pushed the "*I"* key, but if they were different, they pushed the "*z"* key. There were 30 trials each day that participants had to complete. This task measured processing speed and the average reaction time for each correct trial was used in this study.

Covariates

The present study controlled for age and education, which were collected during the intake testing session. Higher education is linked with a lower chance of age-related cognitive decline (Springer et al., 2005). The participants in the present study had a wide range of educational statuses, from high school to tertiary education. As mentioned previously, even in healthy aging, there is a slight decline in cognitive abilities with advanced age (Wilks et al., 2021). Controlling for these two variables gives the ability to more clearly identify if a significant difference is due to test timing and not from differences in educational background or age.

Analysis

Data cleaning and imputation procedures were performed in R (R Core Team, 2020); descriptive analyses and outcome analyses were performed with the Statistical Software Package for the Social Sciences (SPSS, version 28.0, IBM Corp., 2021). I used repeated measures (RM) ANOVA to test 2 hypotheses that explored the effects of test timing group (on-peak, fluctuating, and off-peak hours) on cognitive tasks when controlling for the different days. The interaction effects between day and test timing group, and age and test timing group were also evaluated to test for practice effects and age interaction effects. The cognitive tasks measured episodic memory, working memory, inductive reasoning, and processing speed. For the first hypothesis,

scores from the four cognitive tasks were transformed into t-scores and combined to create a variable (GC) representing the general cognitive ability of the participants (see Table 2).

The decision was made to use the Benjamini-Hochberg (B-H) procedure (Benjamini-Hochberg, 1995) to control the familywise error rate when testing each cognitive task separately. This decreased the chances of type 1 errors without being too conservative when setting the alpha levels. The B-H procedure would increase statistical power and give a more likely chance of detecting actual effects when handling a larger number of tests. The B-H procedure sets alpha values based on the size of the obtained p-values; in the present study, this procedure was used for the analysis regarding the test timing groups and the four separate cognitive tasks. P-values were arranged in ascending order from smallest to largest and ranked 1-4, then its rank order was divided by the total number of tests, multiplied by $\alpha = 0.05$. The formula to determine the critical value for each task was: $\left(\frac{i}{m}\right) Q$ where i = the individual p-value's rank, m = the total number of tests, and Q = the critical value of 0.05.

Table 2

General Cognition (GC) T-scores

	M	*SD*
Fluctuating		
Day 1	199.01	21.92
Day 2	200.59	18.96
Day 3	194.44	16.17
Day 4	201.70	15.12
Day 5	198.02	17.83
Day 6	195.50	13.48
Day 7	197.47	17.73
On-Peak		
Day 1	203.43	22.84
Day 2	203.89	16.38
Day 3	194.46	20.50
Day 4	204.77	15.77
Day 5	203.58	17.24
Day 6	202.67	17.45
Day 7	205.35	18.12
Off-Peak		
Day 1	198.33	20.82
Day 2	204.96	19.16
Day 3	195.21	20.80
Day 4	199.69	17.05
Day 5	201.73	19.68
Day 6	195.91	18.52
Day 7	201.87	20.50

RESULTS

Test Timing Effect on GC

When the analysis was run to test the hypothesis that older adults who performed their cognitive tasks during on-peak hours did better than those who performed them during off-peak or fluctuating times, the value for sphericity was reported at 0.81. This suggests a violation of the assumption of sphericity, so the Greenhouse-Geisser correction was used to adjust for the inequality in variances. This called for an adjusted ANOVA when observing the within-subjects results to account for the violation. Findings did not show significant between-group differences (F (2, 132) = 2.23, p = 0.112), indicating no significant difference in general cognitive scores between the test timing groups. Due to there being no overall difference between the groups, planned contrasts were not assessed. An assessment of the interaction between age and test timing group was conducted to determine if age moderated the effect test timing had on general cognition. However, the analysis showed no significant interaction (F (2,132) = 2.51, p = 0.085). Also, although not of primary interest, the interaction between the day and time group was evaluated to determine if there was significance found between the groups in their change over the seven days (e.g., one group shows practice effects over the week, whereas the other group does not). No significant results were found (F (9.74, 643.06) = 0.33, p = 0.971) for this interaction.

The second hypothesis stated that older adults would perform better on specific cognitive tasks on- versus off-peak and fluctuating times of day (e.g., processing speed more dependent on CR timing than other tasks). However, the test timing group had no significant between-subjects effects for any of the four cognitive tasks (see Table 3). Due to past research regarding CR

changes and age and the possibility of seeing age effects within an older cohort, the interaction effect between age x test timing for each cognitive task was examined to determine if a stronger relationship existed between test timing and cognitive performance relative to a participant's age. However, no significant results were found for this interaction (see Table 3).

Table 3
Between-subject Effects on Cognitive Tasks

	F	*df*	*df* – error	*p*	η^2	α	Power
Backward digit span							
Test timing	0.31	2	132	0.734	0.005	0.0375	0.098
Age interaction	0.367	2	132	0.693	0.006	0.0375	0.108
Object match							
Test timing	0.287	2	132	0.751	0.004	0.05	0.095
Age interaction	0.334	2	132	0.717	0.005	0.05	0.102
Letter series							
Test timing	2.20	2	132	0.115	0.032	0.0125	0.443
Age interaction	2.729	2	132	0.069	0.040	0.0125	0.532
Word recognition							
Test timing	2.16	2	132	0.119	0.032	0.025	0.436
Age interaction	2.224	2	132	0.112	0.033	0.025	0.447

Note. α is adjusted for significance testing per the B-H approach.

Also, although not of primary interest, the interaction between day and time group was evaluated to look for possible practice effects over the individual cognitive tasks (see Table 4). There were no significant results found in this interaction.

Table 4

Within-subjects Effects of Day x Test Timing Group

	Sphericity	*f*	*df*	*df*- Error	*p*	η^2	α	Power
Backward digit span	0.802	1.879	9.622	635.032	0.048	0.028	0.0125	0.263
Object match	0.654	0.838	12	254	0.611	0.038	0.05	0.487
Letter series	0.884	1.114	10.603	699.779	0.348	0.017	0.0375	0.611
Word recognition	0.878	1.828	10.537	695.431	0.049	0.027	0.025	0.863

Note. Object match sphericity = 0.654 meaning multivariate tests were examined for results.

DISCUSSION

The present study aimed to examine the interactions between CR and cognitive performance in older adults when they completed cognitive tasks at different times of day. This study adds to the limited literature regarding CR and its effect on specific cognitive tasks in older adults. I expected the study to reveal a relationship between the time older adults perform cognitive tasks and their scores due to changes in their circadian cycle. The results were generally not significant. There was no significant difference between the test timing groups (i.e., those who performed their cognitive tasks at on-peak vs. fluctuating or off-peak times of day). Additionally, there were no findings that older adults scored significantly higher on one cognitive task at one time of day over another, and there was no significant interaction between age and test time group for any of the cognitive tasks.

Despite the few past findings on the topic (Manly et al., 2002; Wilks et al., 2021), this study did not support the hypothesis surrounding CR and its relationship with cognitive task scores amongst older adults. There were no significant differences between the on- or off-peak or fluctuating testing groups in overall general cognition. This finding could partially be due to the adaptation of the Bielak and colleagues (2019) dataset. First, although I put participants into on-peak, fluctuating, and off-peak groups, our method did not follow standard practice for CR evaluation. The sleep and wake times of participants in this study were not tracked because the project's protocol focused on activity, so I was unable to designate participants as typical morning or evening types. In studies designed to explicitly study CR, participants would be given the MEQ (Horne & Ostberg, 1976), which would determine chronotype, and they would be designated groups based on their responses.

Although the MEQ is one of the most popular ways to determine a person's chronotype, there are criticisms surrounding it because it is self-report and may not be the most appropriate way to measure CR as a multidimensional construct (Levandovski et al., 2013). Pica and colleagues (2013) discussed that the optimal time for a person within their 24-hour circadian cycle and peak mental ability can also be assessed by physiological features such as heart rate and body temperature. However, these aspects were not evaluated in the present study. Research has confirmed that the sleep-wake cycle is responsible for the rise and fall of the 'norm' body temperature, and the morning-ness evening-ness questionnaire generally corresponds with the body temperature peaks and falls (Chauhan et al., 2023). However, in this study, peak ability was designated by the time a participant happened to complete their online tasks. A participant could have been completing tasks when convenient, versus at their cognitive peak, as they were not given any instructions specific to completion time. Past research is conflicting concerning whether older adults' variation in performance between on-and off-peak times is as significant as that found in their younger counterparts. Therefore, this study could add to the current conflicting literature showing that older adults are not as sensitive to time-of-day effects as researchers believe or as their younger counterparts tend to be. Unfortunately, it is impossible to disentangle which outcome and reasoning are correct in the current study.

Subsequently, the analysis revealed that there were no timing group differences when the cognitive tasks were evaluated individually. Within these results, vastly different statistical power percentages for each of the tasks were presented (see Table 4). If the relationship between test timing and one of the cognitive tasks is stronger or more consistent compared to another, it could lead to differences in observed power. The smaller range of values in the two tasks with lower power (object match and backward digit span) leads to less variability within the sample,

and also less potential variability between groups. The backward digit span task had a range of outcome values that was relatively small (only three to eight digits), leading there to be less variability in responses. In the object match task, the variability in reaction times showed to be small between participants and could have been due to objects being relatively similar. With less variability in the data, it decreased the chance of finding significant differences between groups, thereby decreasing statistical power. These small values for statistical power suggest this study may not have been able to detect meaningful timing group effects even if they were present.

There have not been any studies that investigate CR and how it relates to specific cognitive skills within older adults; however, other research showed that morning people's processing speed declines as the day progresses because of the way their neural activity slows (Hines, 2004) and it was assumed that similar results would be found in this study. The reason for not finding significant differences between time groups could have been the hour choices for on- and off-peak testing. Very few studies have looked solely at older adults without younger counterparts to compare, therefore, more research is needed to determine the effect that CR has on cognitive functioning in older adults at different times of the day. Studies regarding CR and cognitive functioning in younger participants generally show best performances in both attention and working memory tasks in the afternoon (Xu et al., 2021). Research in younger adults has also shown that when tested at both on- and off-peak times of day, the off-peak groups generally showed lower attention regulation, higher distractibility, and lower scores on word recall memory tasks (Ngo et al., 2018). The findings from both the current study and those of Wilks and colleagues (2021), who have studied solely older adults, present contradictory results compared to those of younger adults. However, they are also inconsistent with each other. Wilks and colleagues (2021) found that older adults typically show higher cognitive ability in earlier

hours compared to evening hours, whereas the current study did not find these same results. Without further study, I do not know if older adults show the same CR effects on specific cognitive tasks as their younger counterparts. There is the possibility that older adults are less susceptible to time-of-day effects on specific cognitive function domains. Although findings in the present study were nonsignificant, a more controlled approach that gathers all CR information could result in different findings.

One of the primary research questions in the current study was determining if there was an interaction between age and test timing. Does the age of an older participant interact with their circadian rhythm or their peak timing period, and does this change have a more dramatic effect on the cognitive peak the older an individual is? In the primary interaction analysis, age was viewed as a continuous variable because it gave a more precise measurement of its interaction with test timing. However, there was no evidence of interactions between the age of the older participant and CR in relation to their cognitive scores. This suggests that test-timing did not have significantly different effects in the present study based on the ages within the older adult population when testing age as a continuous variable. This finding was unexpected due to research showing CR shifts to become earlier as we age (Cooke & Ancoli-Israel, 2011), meaning that older adults should show higher cognitive peaks earlier in the day, followed by lower points later in the day. Most studies thus far agree that the CR change stabilizes, in healthy aging, around the age of 60, however we do not yet know at what age this phase advance in CR begins (Li et al., 2018).

Measuring age as a continuous variable assumes a linear relationship between age and the outcome being measured. However, the assumption of linearity might not hold true for all age ranges, and there could be specific age groups where the effect of age on the outcome is more

pronounced or different. To test this, I conducted a supplemental analysis to determine if there was a timing group difference between the young-old and old-old cohorts. In this case, age was treated as a dichotomous variable to determine if there was an interaction between age group and test timing. The two groups were made up of participants ages 60 to 69.99 (n = 81), and participants 70 to 89.63 (n = 58). However, there was no evidence of interaction between age group and test timing. Not finding an interaction by age group implies that test timing does not have significantly different effects on the young-old versus old-old cohort.

Finally, analyses did not find a significant interaction between day and time group. There were no discernible differences in the patterns of change over the seven days between the test timing groups. Therefore, the interaction between the day of testing and the time group did not have a meaningful impact on the observed outcomes in the study.

Limitations

There are several limitations to consider within the current study. Participants were able to complete their cognitive tasks at any time during a 24-hour window (Bielak et al., 2019), which meant there was a possibility of them not responding to their survey at a time that truly represented their peak or low point in cognition. Also, because of the 24-hour window restriction, if a participant completed their surveys and tasks at 8 p.m. one day, they could not complete the next one any earlier than that the following day (Bielak et al., 2019). This was to ensure that only one day's worth of activities was captured, but it impacted the ability to examine the link between CR and cognition in the present study.

Due to most of the past research surrounding CR and cognition focusing on younger adults, there were no clear guidelines on the cutoff times for classifying the testing groups. Thus, a range was created. Participants who had completed five or more of their tasks

between 4 a.m. and 11:45 a.m. were classified as on-peak, those who completed five or more of their tasks between 11:46 a.m. and 3:59 a.m. were classified as off-peak, and those who completed less than five tasks in either time group were designated as part of the fluctuating group. In the past, the term 'subjective' has been used when trying to define optimal and non-optimal times of day in studies (Delpouve et al., 2014; Puttaert et al., 2019). When research, like the current study, does not involve lab-controlled CR monitoring, determining a person's chronotype becomes preferential and subjective (Delpouve et al., 2014). The choice to make the range for the on-peak time shorter (i.e., 7 hours 45 minutes) was due to the limited literature pointing to either a cognitive plateau or decline starting around midday (Leirer et al., 1994). Some participants in the dataset completed their tasks at odd hours, (e.g. the middle of the night), so this time had to be accounted for and was labeled as off-peak. To overcome these limitations, participants should be placed into set test timing groups based on their MEQ scores, and the times that they completed their cognitive tasks would have been at reasonable times. However, this was not the case, and because of this, unequal test-timing groups were created, and participants were matched to the closest fitting one.

Throughout the history of research, there has been a tendency to favor and publish findings that demonstrate statistical significance or align with specific hypotheses, leading to an overrepresentation of positive results in the literature (Mlinaric et al., 2017). This phenomenon, known as publication bias, may have contributed to the limited amount of literature available regarding the older adult CR timing change and the effect it may have on cognition. The few existing studies, such as the one by Hasher et al. (2005), showed significant support for a shift in rhythm patterns from young to older adulthood in their investigation of cognitive tasks. It is somewhat surprising that so few studies have been performed on this topic that is directly

relevant to older adults' lives. Therefore, it is possible that these published studies represent only a portion of the research conducted in this area. It is possible that other studies may have investigated similar research questions about CR and cognition but have not been published due to null or non-significant results, like the findings in the current study. If true, non-significance between CR and cognition amongst older adults may in fact be the outcome that is more reliable, meaning the findings in the current study are not necessarily incorrect but rather not yet corroborated by publication.

Conclusions

This study did not find significant differences in on- and off-peak testing of cognitive performance amongst older adults over seven days. Further, participant age did not interact with test timing in relation to cognitive task scores. These findings illustrate many of the limitations of secondary research analysis and the need for more well-controlled studies in the area of CR and cognition that exclusively contain older adults. Early detection and diagnosis of brain diseases such as dementia are vital for the slowing of progression and symptom management (Rasmussen & Langerman, 2019). If researchers can pinpoint a more solid on-peak test time for their older participants, then practitioners who are testing cognition may be able to detect decline earlier in the disease process.

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