Synchrony Affects Performance for Older but not Younger Neutral-Type Adults

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Abstract

Circadian rhythms influence performance on a broad range of cognitive tasks, including attention shifting, implicit learning, memory retrieval, suppression of distracting information, creativity, and problem solving. Much of the research on circadian arousal and cognition has examined the consequence of testing individuals at times that are synchronous or asynchronous with their personal circadian peaks. To date, the studies examining these synchrony effects in cognitive function have focused primarily on the performance of individuals who show strong morningness or strong eveningness tendencies; little is known about individuals with neutral chronotypes and whether their performance varies over the day. The lack of data on neutral types is a serious gap in our knowledge, as up to 60% of young adults and 25% of older adults do not show strong morning or evening preferences. The present study assessed the performance of neutral-type younger and older adults at three times of day (early morning, midday, and evening) on a battery of cognitive tasks, including inhibitory processing, executive function, memory, perceptual speed, and access to well-learned knowledge. Older neutral-types showed synchrony effects for inhibitory processing, executive function, long-term memory, and forgetting, and generally had best performance on these tasks at midday. Consistent with other findings, older neutral-types showed no synchrony effects for measures of general knowledge and perceptual speed. Younger neutral-types, by contrast, showed no effects of time of testing on performance over the day for any measure, suggesting greater cognitive flexibility over the day relative to younger evening-types, older morning-types, or older neutral-types.

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1. Introduction

Circadian rhythms are daily fluctuations in biological and psychological functions that influence an array of human behaviors, including sleep-wake patterns, subjective alertness, mood, eating habits, blood pressure, hormone secretion, exercise, and brain and cognitive function (e.g., Anderson et al., 2014; Blatter & Cajochen, 2007; Horne & Ostberg, 1976; Hrushesky, 1994; Mongrain et al., 2006; Schmidt et al., 2007; Tankova et al., 1994; Van Dongen & Dinges, 2005). These rhythms are influenced by exogenous factors like sunlight and work schedules, as well as endogenous factors that drive individual differences and developmental shifts in circadian arousal patterns (e.g., Carskadon et al., 1993; Kim et al., 2002; May et al., 1993; Roenneberg et al., 2004, 2007; Schmidt et al., 2007).

Several different methods have been used to measure individual differences in circadian patterns, including monitoring of fluctuations in body temperature over 24-hour cycles, subjective alertness across the day, and self-report instruments that assess sleep-wake behaviors and preferences (Folkard et al., 1979; Horne & Ostberg, 1976; Mecacci & Zani, 1983; Torsvall & Akerstedt, 1980). One of the first and still most widely used measures of circadian arousal is the Morningness–Eveningness Questionnaire (MEQ), a 19-item survey developed by Horne and Ostberg (1976). Scores on the MEQ correlate significantly with other self-report measures (e.g., Greenwood 1991, 1994, 1995; Smith et al., 1989), and with physiological measures of arousal like hormone secretion and body temperature (e.g., Buela-Casal et al., 1990; Horne & Ostberg, 1977; Roenneberg et al., 2003; Smith et al., 1989). The MEQ has been translated into several different languages, has been used to assess circadian patterns across the adult lifespan, and has proven to be a reliable and valid measure of circadian patterns (Buela-Casal et al., 1990; Kerkhof, 1984; Smith et al., 1989).

Scores on the MEQ classify individuals as one of five chronotypes: definitely morning, moderately morning, neutral, moderately evening, and definitely evening. People with a morningness chronotype experience their optimal arousal level early in the day and prefer to engage in challenging cognitive and physical activities in the morning, while those with an eveningness chronotype experience their optimal arousal level later in the day and prefer to reserve tasks that are intellectually or physically demanding for afternoon and evening hours. Neutral-type individuals show neither strong morningness nor strong eveningness preferences, and experience a peak in body temperature that is somewhere between that of morning-types and evening-types (Adan & Guardia, 1993; Horne, Brass, & Petitt, 1980; Kerkhof, 1998; Natale & Cicogna, 2002; Roenneberg et al., 2007).

Data from the MEQ and other similar measures indicate developmental shifts in circadian preferences over the lifespan. Young children tend to be morning-types, but there is a shift towards eveningness in adolescence (e.g., Carskadon et al., 1993, 1998; Crowley et al., 2007; Ishihara et al., 1990; Kim et al., 2002).

While many young adults show an eveningness preference, there is another developmental shift back towards morningness after the age of 50 (Baehr et al., 2000; Czeisler et al., 1986; Diaz-Morales & Sorroche, 2008; May & Hasher, 1998; May et al., 1993; Mecacci et al., 1986; Roenneberg et al., 2007).

Individual and developmental differences in circadian arousal patterns are significant because these patterns affect performance on a number of cognitive tasks, such that individuals perform best when testing occurs during their optimal time. This finding, known as the synchrony effect (May & Hasher, 1998 ; May et al., 1993), has been observed for a variety of visual and verbal memory tasks (e.g., Fabbri et al., 2013; Intons-Peterson et al., 1999; May et al., 1993; Petros et al., 1990; Yoon, 1997), problem solving tasks (May, 1999), working memory tasks (e.g., Rowe et al., 2009; Yoon et al., 1999), executive function tasks (e.g., Goldstein et al., 2007; Hahn et al., 2012; May & Hasher, 1998; Schmidt et al., 2007), verbal fluency (e.g., Iskandar et al., 2016), rejection of false memories (Intons-Peterson et al., 1999), narrative comprehension (Natale & Lorenzetti, 1997), reliance on stereotypes (e.g., Bodenhausen, 1990), analytic processing (Hossain & Saini, 2014), and rejection of irrelevant information and responses (e.g., Hasher, Chung, May & Foong, 2002; Hasher, Zacks, & May, 1999; Intons-Peterson et al., 1998; May, 1999; May & Hasher, 1998; Schmidt et al., 2012). For all these tasks, evening-types show better performance in the evening relative to the morning, and morning-types show better performance in the morning relative to the evening.

It is important to note that not all cognitive tasks show a benefit of circadian synchronization. The advantages observed when testing times align with an individual's optimal time of day are most prevalent for demanding tasks that require careful, strategic processing and the rejection of fluid, well-learned responses in favor of less dominant but contextually appropriate ones (Bodenhausen, 1990; Hasher et al., 2002, 2005; May & Hasher, 1998). Synchrony effects are generally absent on tasks in which participants can rely on familiar, well-learned knowledge and when the dominant response is correct (e.g., Hasher et al., 1999; May & Hasher, 1998), as is seen, for example, on tests of vocabulary, processing speed, and lexical access (e.g., Borella et al., 2010; Hasher et al., 2005; May & Hasher, 1998; Song & Stoughton, 2000). In addition, asynchrony effects have been observed for tasks that involve implicit, unconscious processes, or when access to distracting information proves beneficial (e.g., Delpouve et al., 2014; May et al., 2005; Rowe et al., 2006; Weith & Zacks, 2011).

The vast majority of studies that have reported synchrony (or asynchrony) effects in cognitive function have focused on individuals who show strong morningness and/or strong eveningness tendencies, and these studies have utilized early morning and late afternoon or evening testing times. Little is known about neutral-type individuals and whether their performance varies over the day. Thus despite the now well-documented finding that aligning testing times with individual differences in circadian arousal can significantly improve (or in some cases,

impair) performance on different intellectual tasks, there remains a serious gap in our understanding of these effects. This gap is especially concerning given that up to 60% of younger adults and 25% of older adults fall somewhere between the extreme ends of the morningness-eveningness scale and are considered neutral-types (Achari & Pati, 2007; Cavallera & Giudici, 2008; Lacoste & Wetterberg, 1993; May & Hasher, 1998; Natale & Cicogna, 2002).

The purpose of the present study was thus to assess the performance of neutral-type younger and older adults on a variety of cognitive measures over the day. Participants completed a number of tasks that are known to show synchrony effects for morning-type and evening-type individuals, including measures of inhibitory control (sentence completion task by Hartman & Hasher, 1991), executive function (Stroop and Trails effects), and immediate and delayed memory (Logical Memory I and II). We also included measures for which performance of morning-type and evening-type individuals tends to remain stable over the day, including access to well-learned, general knowledge (vocabulary, high-cloze sentence completion, color naming), and processing speed (Trails A, Letter Comparison Task). Because neutral-type individuals tend to report a 'best time' of day near midday, we included three different testing times: early morning (8:00 am), midday (12:00 pm), and early evening (5:00 pm). If the performance of neutral-type individuals is governed by the synchrony between chronotype and testing time as it is for morning-types and evening-types, we expected to observe best performance at midday relative to morning and evening testing times. Because aging has a significant impact on the circadian arousal system (Schmidt et al., 2007), the magnitude of the synchrony effect has been reported to be greater for morning-type older than evening-type younger adults (e.g., Borella et al., 2010; Lehmann et al., 2013; Li et al., 1998; May & Hasher, 1998; West et al., 2002), and thus we expected that synchrony effects may be greater for neutral-type older relative to neutral-type younger adults.

2. Methods

2.1. Participants

Participants included 94 younger adults (ages 17–21 yrs.) from the University of Arizona and the University of Toronto, and 72 healthy, community-dwelling older adults (ages 60–74 yrs.). Younger adults were students enrolled in an introductory psychology course who participated as one way of fulfilling a course requirement, and older adults were recruited through newspaper advertisements and senior activity centers. Older adults provided their own transportation and received free parking and monetary compensation for their participation.

All participants were screened for neutral chronotype using the Horne Ostberg Morningness Eveningness Questionnaire (MEQ; Horne, & Ostberg, 1976). The MEQ consists of 19 questions that assess individuals' sleep-wake behaviors and preferences. Scores on the MEQ correlate with physiological measures of arousal (e.g., Buela-Casal et al., 1990; Roenneberg et al., 2003; Smith et al., 1989), and the MEQ has been widely used to assess circadian preferences in younger and older

adults (Baehr et al., 2000; Czeisler et al., 1986; May & Hasher, 1998; Mecacci et al., 1986; Roenneberg et al., 2007). All young adults completed the MEQ as part of a large battery of surveys at the start of the semester, and all older adults completed the MEQ as part of a mailed survey. All participants also completed a health and education questionnaire as well as a measure of verbal ability (Extended Range Vocabulary Test, ERVT; Educational Testing Service, 1976) at the time of testing.

2.2. Materials

2.2.1. Hartman & Hasher (1991) Sentence Completion Task

Materials for the sentence completion task were adopted from those developed by Hartman and Hasher (1991). This task consists of two phases. In Phase 1, participants first generate highly-probable endings to sentences. Some of these endings are rejected and replaced by the experimenter with new target endings, which participants are to remember for a later memory test. In Phase 2, priming for both the rejected endings and the new target endings is assessed with an indirect test.

Forty-two sentences with highly predictable endings (e.g., "She ladled the soup into her ___." Expected ending: 'bowl') were used in Phase 1. These sentence frames have been normed with both younger and older adults to have an approximate cloze value of 0.85 (i.e., 85% of participants generate the expected endings).

Twenty-eight of the 42 high-cloze sentences served as critical items in Phase 1. For those critical sentences, the high-probable endings were disconfirmed and replaced by a low-probable but plausible target ending that participants were to remember (e.g., 'lap' for the sentence, "She ladled the soup into her ___."). The 28 critical sentences were divided into two groups of 14, and each participant saw only one group of 14 critical items in Phase 1. The two subsets of critical items were used equally often across age groups and testing times.

The remaining 14 of the 42 high-cloze sentences served as filler items for all participants in Phase 1. For these filler items, participants were instructed to remember the highly-predictable endings. Thus for half the items in Phase 1, participants were instructed to remember highly-probable endings, and for the remaining half participants were instructed to reject the highly-probable endings and remember low-probable endings instead. The highly-probable endings (e.g., 'bowl') and the low-probable target endings (e.g., 'lap') were relatively equal with respect to frequency (Kucera & Francis, 1967).

Phase 1 also included two additional high-cloze sentences that were used as practice items for all participants. These practice items appeared at the start of Phase 1 and were the same for all participants.

Materials for Phase 2 of the sentence completion task included 28 pairs of sentences developed for the critical items from Phase 1. All of these sentences were moderate-cloze (0.50) sentences (i.e., 50% of participants in a normative studied generated the expected ending). One sentence in each pair was designed to be moderately predictive of the high-cloze, disconfirmed ending (e.g., 'bowl'), and the other was designed to be moderately predictive of the new target ending (e.g., 'lap'). A total of 56 moderate-cloze sentences were used in Phase 2, and every participant saw every sentence. For each participant, 28 of the 56 sentences served as control items and could be completed with words not presented in Phase 1. The remaining 28 sentences could be completed with words from Phase 1 (14 disconfirmed items and 14 target items). The control and critical items were counterbalanced across participants such that items served as critical and control an equal number of times across age groups and testing times. The critical measures in this task were target priming and disconfirmed priming, calculated as the frequency with which participants used target and disconfirmed items, relative to control items, to complete the moderate-cloze sentence frames.

2.2.2. Stroop Task

Materials for the Stroop (1935) task included three separate cards: one with 100 color patches (red, green, and blue), one with 100 color names printed in black ink, and one with 100 Stroop color

words, that is, color names printed in an ink of a different color. The participants' task was to name the stimuli on each page as quickly as possible, and naming time for each page was recorded. The Stroop effect was calculated as the difference in naming time for the Stroop color-word page versus the color-patch page.

2.2.3. Trails A and B

The Trail Making Test (Reitan, 1958) consists of two parts, A and B. Part A measures the time required to draw lines connecting numbers that are randomly displayed on a page into a numeric sequence (i.e., 1 to 2 to 3 to 4, etc.). Part B measures the time required to draw lines connecting numbers and letters that are randomly displayed into an alphanumeric sequence (i.e., 1 to A to 2 to B to 3, etc.). The Trail Making effect was calculated as the difference in time needed to complete Parts B and A.

2.2.4. Logical Memory

The Logical Memory test is a subtest of the Wechsler Memory Scale—Revised (1987) that provides an assessment of both immediate (LMI) and delayed (LMII) recall. The task includes a short narrative that is read aloud, and participants are tested immediately (LMI) and again after a delay (LMII). In the present study we used Story A and a delay of 30 minutes. A forgetting score was determined for each participant by first calculating the difference in scores for LMI versus LMII, and dividing that difference by the score on LMI.

2.2.5. Perceptual Speed

Perceptual speed was assessed with a paper-and-pencil version of the Letter Comparison task (Salthouse & Babcock, 1991) that required participants to make same/different decision about pairs of three, six or nine letters. Three separately timed trials were administered, and the number of correct responses on each trial was averaged to produce a single perceptual speed score.

2.3. Procedure

One third of the participants in each age group were randomly selected to participate in the morning (8:00 am), one-third at midday (12:00 pm), and one-third in the evening (5:00 pm). Participants first completed a consent form, and then completed the experimental tasks in the following order: Phase 1 of the sentence completion task, Health and Education Questionnaire, Stroop (1935) task, Trail Making Test (Reitan, 1958), Phase 2 of the sentence completion task, Logical Memory I, Perceptual Speed (Salthouse & Babcock, 1991), Logical Memory II, and the ERVT (Educational Testing Service, 1976).

For Phase 1 of the sentence completion task, participants read 30 normatively high-cloze sentence frames (2 practice, 14 critical, and 14 filler). Sentences appeared in a white font on a black background in the center of the computer screen. Before each sentence appeared, a fixation cross was presented for 750 ms. After the fixation, the entire sentence appeared at once, minus the final word. A blank space appeared in place of the final word. Participants were told to generate the most likely ending for the sentence, and the frame remained onscreen until the participant generated an ending into a microphone. The experimenter recorded the participant's response. At that point, the 'final' word for the sentence appeared onscreen for 400 ms. For filler items, the 'final' word was the participant-generated expected ending; for critical sentences, the 'final' word was the alternative, low-probable target ending. The entire sentence plus the final ending then appeared onscreen for an additional 2000 ms. Participants were instructed to remember the 'final' word generated by the computer for a later memory task.

After Phase 1 of the sentence completion task, participants completed a health and education questionnaire, the Stroop (1935) task, and the Trail Making Test (Reitan, 1958). The Stroop and the Trails were administered in the standard formats. Participants then completed the indirect memory

test for the critical words from the initial phase of the sentence completion task. Participants were told that the purpose of the indirect test was to create stimuli for use in a future experiment.

For the indirect test in the sentence completion task, participants generated aloud endings for 56 medium-cloze sentences frames. Unbeknownst to participants, 14 of these sentences could be completed with the highly-predictable but disconfirmed endings (e.g., 'bowl') from Phase 1, 14 could be completed with the alternative target endings (e.g., 'lap'), and 28 were control items that could be completed with words never seen in Phase 1. Participants read each sentence aloud and generated the first word that came to mind as an ending for the sentence. Each sentence remained onscreen until the participant responded, and the experimenter recorded the response. The question of interest was whether participants generated the disconfirmed endings and the alternative target endings from Phase 1 more often than they generated the control items.

Upon completion of Phase 2 of the sentence completion task, Logical Memory I was administered. Participants then completed the Letter Comparison task and several nonverbal filler tasks so that the delay between LMI and LMII was consistently 30 minutes. Participants completed LMII and finally took the ERVT.

3. Results

3.1. Participants

Demographic information, including MEQ, ERVT, years of education, and age can be found in Table 1. Two younger adults (one tested midday and one in the evening) and one older adult (tested in the morning) reported some awareness of the relation between the two parts of the sentence completion task. Their data were replaced with data from three new, naïve participants. Young adults (*M* age = 19.1 yrs.) had an average of 13.1 years of education, a mean score of 22.4 on the ERVT, and an average MEQ score of 49.1, which placed them in the range of neutral

Table 1.
Mean age, MEQ score, years of education, and Verbal Ability Scores for each age group and testing time (and standard deviations).

Age group	Age	MEQ	Years of education	ERVT
Younger adults				
8:00 am	19.1 (1.4)	48.6 (3.7)	13.3 (1.4)	22.8 (8.1)
12:00 pm	18.7 (0.92)	50.2 (4.1)	12.8 (1.0)	20.1 (8.9)
5:00 pm	19.3 (1.4)	48.5 (4.6)	13.3 (1.4)	24.3 (8.1)
Older adults				
8:00 am	67.8 (4.4)	52.7 (3.8)	15.5 (2.7)	31.1 (6.2)
12:00 pm	68.2 (3.9)	51.4 (5.2)	15.6 (2.7)	34.1 (9.8)
5:00 pm	67.7 (4.0)	51.9 (5.1)	16.0 (2.5)	34.2 (7.5)

types. Older adults (*M* age = 67.7 yrs.) had significantly more years of education (*M* = 15.7), $F(1,162) = 68.9$, $p < 0.001$, $\eta^2 = 0.30$, a significantly higher score on the ERVT (*M* = 33.1), $F(1,162) = 70.1$, $p < 0.001$, $\eta^2 = 0.30$, and a mean MEQ score of 51.98, which placed them in the range of neutral-types. There were no main effects or interactions with testing time for these measures.

3.2. Sentence Completion Task

As seen in Table 2, generation rates for the expected endings of critical sentence frames in Phase 1 of the sentence completion task were all above 88%. Completion rates did not differ across age groups or testing times (all *F*s < 1). Although these scores are close to ceiling, there is no suggestion of a synchrony effect on completion of hi-cloze frames for either age group. For all critical sentence frames in which a participant failed to generate the expected ending in Phase 1, the corresponding pair of moderate-cloze frames in Phase 2 was omitted from analyses.

Completion rates for the control, distractor, and target endings in Phase 2 can be seen in Table 2. The first step in the analysis of completion rates for Phase 2 was to compare control sentence completion rates across age groups and testing times. A 2 (Age) × 3 (Testing Time) analysis of variance (ANOVA) indicated no main effects or interactions of age and testing time on completion rates for the control sentence frames (*F*s < 1), suggesting that younger and older adults were equally likely to complete the control frames with the normative endings at each testing time. Thus, the baseline control scores were equivalent for all groups, enabling the remaining tests to be calculated on priming effects (i.e., the difference
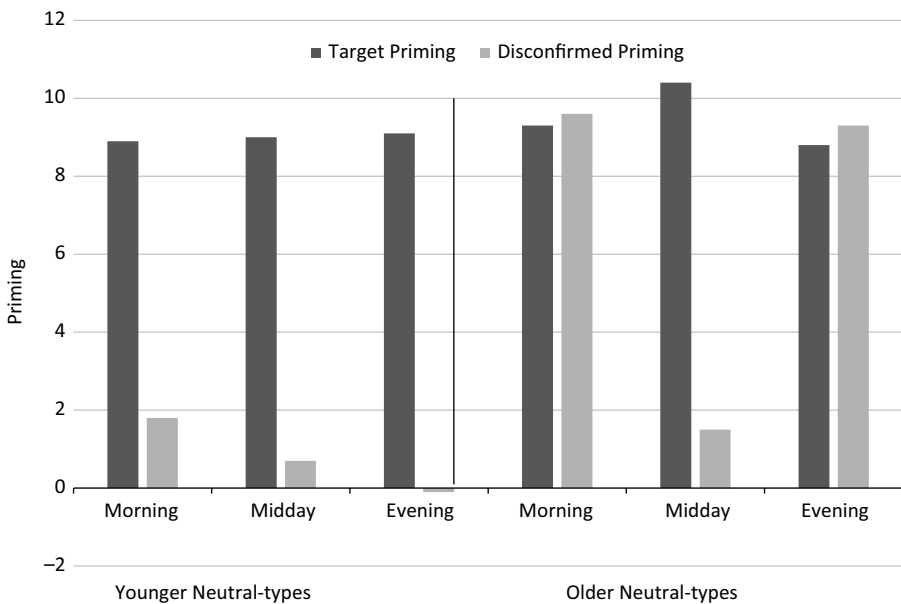
Table 2.

Mean completion rates (and standard deviations) for high-cloze sentences frames in Phase 1 and moderate-cloze sentence frames (Control, Target, and Distractor) in Phase 2 for each age group and testing time.

Age group	High-cloze (%)	Moderate-cloze (%)		
		Control	Target	Distractor
Younger adults				
8:00 am	90.2 (8.5)	48.1 (8.9)	57.0 (15.9)	49.9 (10.6)
12:00 pm	91.3 (8.9)	46.6 (8.1)	55.6 (14.9)	47.3 (12.2)
5:00 pm	89.9 (8.2)	50.6 (9.3)	59.7 (12.8)	50.5 (13.5)
Older adults				
8:00 am	88.2 (7.1)	48.8 (10.3)	58.1 (14.4)	58.4 (14.9)
12:00 pm	89.3 (9.4)	47.7 (9.1)	58.1 (10.3)	49.2 (18.0)
5:00 pm	91.2 (11.0)	47.0 (11.5)	55.8 (13.7)	56.3 (16.7)

between target and control completion rates, and between distractor and control completion rates, with the difference calculated for each individual participant).

Target and distractor priming effects for each age group and testing time are depicted in Fig. 1. To assess target priming effects, an initial 2 (Age) × 3 (Testing Time) ANOVA was conducted on target priming scores. As can be seen in Fig. 1, both younger and older adults showed target priming across every testing time, and there were no main effects of age or testing time, and no interaction ($Fs < 1$). Thus both age groups kept relevant target information active in mind, and the ability to do so did not differ at peak versus off-peak times for neutral-type individuals. Distractor priming, by contrast, showed a main effect of age, $F(1,162) = 7.0$, $p < 0.01$, $\eta^2 = 0.04$, but no main effect of testing time, $F(2,162) = 1.1$, $p = 0.33$. Further analyses indicated that younger neutral-types showed no significant distractor priming at any time of day ($Fs < 1$), suggesting that they were successful in suppressing their self-generated but now-obsolete responses. Older adults, however, showed reliable distractor priming both in the morning ($M = 8.1$) and the evening ($M = 9.3$), $F(1,23) = 9.5$, $p < 0.005$, $\eta^2 = 0.30$ and $F(1,23) = 10.6$, $p < 0.003$, $\eta^2 = 0.32$, respectively, but not at midday ($M = 1.6$), $F < 1$. These findings suggest that neutral-type older adults tested at off-peak times fail to suppress items that become obsolete and are no longer relevant for the current context, and consequently those items remain active in memory.

Figure 1. Mean target and disconfirmed priming scores for younger and older neutral-types at each testing time.

3.3. Stroop Task

Mean naming times for the color, word, and Stroop cards are displayed in Table 3. To assess the effects of Age and Testing Times, response times for each card were assessed with a 2 (Age) × 3 (Testing time) ANOVA. For the color card, younger adults were significantly faster than older adults in naming color patches, $F(1,162) = 45.0$, $p < 0.001$, $\eta^2 = 0.22$. There was neither a main effect nor an interaction with testing time, $Fs < 1$, suggesting that synchrony does not affect the speed of naming color patches for younger or older neutral-type adults.

The pattern of data for the word card mirrored those of the color card. Younger adults were significantly faster than older adults in reading color words, $F(1,162) = 21.0$, $p < 0.001$, $\eta^2 = 0.12$, but there was neither a main effect nor an interaction with testing time, $Fs < 1$. These data align with the color patch data in suggesting that synchrony does not affect speeded access to well-learned information for neutral-type younger and older adults.

For the Stroop card, there was a main effect of age, $F(1,162) = 127.3$, $p < 0.001$, $\eta^2 = 0.44$, with younger adults significantly faster than older adults. There was also a significant effect of testing time, $F(2,162) = 4.2$, $p < 0.02$, $\eta^2 = 0.05$, which was qualified by a reliable age × testing time interaction, $F(2,162) = 3.3$, $p < 0.04$, $\eta^2 = 0.04$. Young adults showed no effect of testing time on Stroop naming, $F < 1$. Older adults, however, did show a main effect of testing time, $F(2,69) = 4.1$, $p < 0.02$, $\eta^2 = 0.11$, and they were significantly faster to respond to Stroop stimuli in the morning and at midday than they were in the evening, $F(1,46) = 4.9$, $p < 0.03$, and

Table 3.

Mean response times (and standard deviations) for the color card, word card, Stroop card, Trails A, and Trails B for each age group and testing time.

Age group	Stroop				Trail Making Test		
	Color	Word	Stroop	Stroop effect	Trails A	Trails B	Trails effect
Younger adults							
8:00 am	53.9 (7.1)	41.4 (7.2)	88.0 (13.6)	34.1 (10.6)	24.7 (9.4)	48.0 (12.3)	23.3 (14.1)
12:00 pm	54.0 (7.4)	40.8 (4.6)	86.9 (12.7)	32.9 (10.7)	22.1 (5.6)	48.1 (12.3)	26.6 (11.3)
5:00 pm	52.7 (7.7)	40.4 (5.9)	88.3 (15.8)	35.6 (13.8)	23.0 (6.3)	47.6 (14.1)	24.6 (12.7)
Older adults							
8:00 am	64.2 (10.8)	46.4 (7.3)	116.6 (19.7)	52.4 (17.6)	34.6 (11.0)	87.1 (24.7)	52.5 (19.5)
12:00 pm	61.2 (9.7)	44.7 (7.8)	113.7 (22.9)	52.5 (18.3)	31.6 (9.3)	69.7 (22.0)	38.1 (19.5)
5:00 pm	62.0 (8.8)	45.8 (7.5)	131.9 (27.5)	69.9 (26.0)	33.3 (11.2)	88.5 (33.8)	55.2 (28.9)

$F(1,46) = 6.2, p < 0.02$, respectively. There was no difference in response times for the morning versus midday, $F < 1$.

The Stroop effect was calculated as the difference in response time for the Stroop card relative to the color card. As expected, younger adults showed a reliably smaller Stroop effect than did older adults, $F(1,162) = 93.8, p < 0.001, \eta^2 = 0.37$. As with the Stroop naming, there was a reliable effect of testing time on the Stroop effect, $F(2,162) = 6.0, p < 0.004, \eta^2 = 0.07$, and this main effect was qualified by an age × testing time interaction, $F(2,162) = 3.6, p = 0.03, \eta^2 = 0.04$. For younger adults, the Stroop effect did not vary significantly across testing times, $F < 1$. By contrast, older adults showed a significant effect of testing time, $F(2,69) = 5.0, p < 0.01, \eta^2 = 0.13$, with reliably smaller Stroop effects in the morning and midday than in the evening, $F(1,46) = 6.9, p < 0.01$ and $F(1,46) = 6.3, p < 0.02$, respectively. There was no difference in the Stroop effect shown by neutral-type older adults tested in the morning versus midday, $F < 1$.

3.4. The Trail Making Test

Response times for Parts A and B of the Trail Making Test are presented in Table 3. For Part A, a 2 (Age) × 3 (Testing Time) ANOVA indicated a reliable main effect of age, $F(1,162) = 52.3, p < 0.001, \eta^2 = 0.24$, with younger adults responding more quickly than older adults. As with the color and word cards in the Stroop task, there was no main effect of testing time, $F < 1$, nor was there an age × testing time interaction, $F < 1$. These data suggest that synchrony had no impact on individual's speed for connecting dots in numerical order, just as it had no impact on color or word naming.

For Part B, a 2 (Age) × 3 (Testing Time) ANOVA showed a main effect of age, $F(1,162) = 111.5, p < 0.001, \eta^2 = 0.41$, with younger adults again responding more quickly than older adults. There was a main effect of testing time, $F(2,162) = 3.4, p < 0.04, \eta^2 = 0.04$, as well as an age × testing time interaction, $F(2,162) = 3.7, p < 0.03, \eta^2 = 0.04$. Younger neutral-types showed no effect of testing time on response time for Part B, $F < 1$. Older adults, by contrast, showed a reliable effect of testing time, $F(2,69) = 3.6, p < 0.04, \eta^2 = 0.09$, such that responses at midday day were significantly faster than those in the morning, $F(1,46) = 6.7, p < 0.02$, or evening, $F(1,46) = 5.3, p < 0.03$. There was no difference in response times on Part B for older neutral-types tested in the morning versus evening, $F < 1$.

The Trail Making effect was calculated as the difference in response time for Part B versus Part A. Younger adults showed a reliably smaller Trail Making effect than older adults, $F(1,162) = 74.0, p < 0.001, \eta^2 = 0.31$. There was also a marginal testing time effect, $F(2,162) = 2.9, p = 0.061, \eta^2 = 0.03$, which was qualified by a significant age × testing time interaction, $F(2,162) = 4.6, p < 0.02, \eta^2 = 0.05$. While younger neutral-types showed no effect of testing time on the Trail Making effect, $F < 1$, older adults showed a reliable effect, $F(2,69) = 3.8, p < 0.03, \eta^2 = 0.10$. Further analyses showed that, similar to the Stroop effect, the Trail Making

effect for older neutral-types was significantly smaller at midday than in the morning, $F(1,46) = 6.6, p < 0.02$, or the evening, $F(1,46) = 5.8, p < 0.02$.

3.5. Logical Memory I and II

Scores on the Logical Memory I (immediate memory) and II (delayed memory), as well as a measure of forgetting, are presented in Table 4. The forgetting score was determined by first calculating the difference between LMI and LMII for each participant, and then dividing that difference by the individual's LMI score.

For LMI, younger adults generally remembered more than older adults, $F(1,162) = 22.8, p < 0.001, \eta^2 = 0.12$. There was no testing time effect, $F < 1$, nor was there an age × testing time interaction, $F < 1$, suggestion that synchrony did not affect immediate memory for younger or older neutral-type adults.

For LMII, younger adults again outperformed older adults, $F(1,162) = 39.1$, $p < 0.001$, $\eta^2 = 0.20$. The effect of Testing Time failed to reach significance, $F(2,162) = 2.1, p = 0.13$, but there was a reliable age × testing time interaction, $F(2,162) =, p < 0.03, \eta^2 = 0.05$. Further analyses indicated no effect of testing time for younger adults, $F(2,93) = 1.1, p = 0.33$, but a reliable main effect for older adults, $F(2,69) = 4.1, p < 0.02, \eta^2 = 0.11$. Older neutral-types tested at midday had scores that were reliably higher than those tested in the evening, $F(1,46) = 6.5$, $p < 0.02$. The difference between midday and morning scores was not reliable, $F(1,46) = 1.8, p = 0.19$, though the difference between morning and evening approached significance, $F(1,46) = 3.0, p = 0.09$.

Finally, with respect to our measure of forgetting, younger adults forgot reliably less than older adults across over the delay, $F(1,162) = 12.6, p < 0.001, \eta^2 = 0.07$.

Table 4.
Mean scores (and standard deviations) for Logical Memory I, Logical Memory II, Logical Memory Forgetting, and the Letter Comparison task for each age group and testing time.

Age group	LMI	LMII	LM Forgetting*	Letter Comparison
Younger adults				
8:00 am	28.3 (7.5)	23.6 (8.5)	18% (0.16)	68.6 (9.2)
12:00 pm	26.3 (7.6)	21.8 (9.7)	20% (0.18)	69.1 (8.4)
5:00 pm	28.4 (7.1)	25.0 (8.2)	13% (0.17)	67.3 (7.8)
Older adults				
8:00 am	21.8 (3.8)	16.2 (3.9)	26% (0.13)	49.3 (8.8)
12:00 pm	22.5 (7.2)	18.3 (6.3)	19% (0.18)	50.6 (10.0)
5:00 pm	22.9 (8.1)	13.5 (6.7)	39% (0.30)	49.5 (8.7)

* LM Forgetting was determined by calculating the difference between LMI and LMII, and dividing that difference by LMI.

While the effect of testing time was not significant, $F(2,162) = 1.5$, $p = 0.23$, there was a significant age × testing time interaction, $F(2,162) = 6.9$, $p < 0.001$, $\eta^2 = 0.08$. Further analyses indicated no effect of testing time for younger adults, $F(2,93) = 1.4$, $p = 0.26$, but a reliable testing time effect for older adults, $F(2.69) = 5.4$, $p < 0.008$, $\eta^2 = 0.14$. Older neutral-types showed reliably less forgetting when tested at in the morning and at midday than when tested in the evening, $F(1,46) = 4.0$, $p < 0.05$ and $F(1,46) = 7.9$, $p < 0.007$, respectively. The difference in forgetting for neutral-type older adults tested in the morning versus midday failed to reach significance, $F(1,46) = 2.2$, $p = 0.14$.

3.6. Letter Comparison Task

Scores on the Letter Comparison Task are presented in Table 4. Younger neutral-types completed more of the same/different comparisons than older neutral-types, $F(1,162) = 184.4$, $p < 0.001$, $\eta^2 = 0.53$. There was no main effect of Testing Time, $F < 1$, nor was there an age × testing time interaction, $F < 1$, suggesting that speed of processing did not vary over the day for younger or older neutral-types.

4. Discussion

To date, no study has systematically assessed cognitive functioning over the day for individuals with a neutral chronotype, despite the fact that cross-cultural normative data indicate that a majority of younger adults (up to 60%) and a significant minority of older adults (roughly 25%) are neutral-types (Achari & Pati, 2007; Cavallera & Giudici, 2008; Lacoste & Wetterberg, 1993; May & Hasher, 1998; Natale & Cicogna, 2002). The purpose of the present investigation was to examine the performance of neutral-type younger and older adults across the day on tasks that have previously shown robust synchrony effects for morning-type and evening-type individuals, including tests of inhibitory processing, executive function, and verbal memory. We also tested neutral-type individuals on tasks that have shown no synchrony effects in previous studies, including tests of vocabulary, general knowledge, and perceptual speed. The general pattern of findings from this study suggests that the cognitive functioning of younger neutral-type individuals shows little sensitivity to synchrony effects, as there were no differences in performance over the day on any measure. By contrast, the data from older neutral-types mirrored findings of older morning-types in previous studies, as they showed reliable effects of testing time on measures of inhibitory processing, executive function, and long-term memory, and consistent performance over the day for measures of vocabulary, general knowledge, and processing speed.

Our measures of inhibitory processing and executive function included suppression of no-longer-relevant words in the Hartman and Hasher (1991) sentence completion task, the Stroop (1935) effect, and the Trail Making effect. Previous research demonstrates not only that younger adults outperform older adults

on these sorts of measures, but also that both younger evening-type and older morning-type individuals show synchrony effects for distractor suppression and executive function (e.g., Hasher et al., 1999; Intons-Peterson et al., 1998; Iskandar et al., 2016; May, 1999; May & Hasher, 1998; Schmidt et al., 2007). Thus we expected to see a similar pattern here for younger and older neutral-types. Contrary to these expectations, the performance of younger neutral-types did not vary on any of these measures across the three testing times included in this study, suggesting that neutral-type younger adults may be more flexible in their cognitive processing over the day than evening-type younger adults. Consistent with our expectations, however, older neutral-types not only showed significant age-related deficits on all measures, but also showed reliable synchrony effects on each task. In the sentence completion task, older neutral-types showed reliable priming for obsolete, rejected items in the morning and in the evening, but did not show significant priming for those items at midday. In the Stroop task, older neutral-types had a reliably larger Stroop effect in the evening than at midday, though performance in the morning was similar to that at midday. Finally, older-neutral types had a larger Trail Making effect in the evening and the morning than at midday. Together, these data suggest that neutral-type older adults tested at midday, likely their best time of day, are more successful than others tested in the morning or evening at suppressing items that become irrelevant, at blocking out competing responses, and in shifting attention from one type of information to another.

The pattern of findings for our verbal memory assessment showed a similar pattern to the data for inhibitory processing and executive function. Younger neutral-types outperformed older neutral-types on all measures, but showed no effect of synchrony on immediate memory (LMI), long-term memory (LMII), or forgetting. These data further demonstrate that neutral-type younger adults are less susceptible to synchrony effects than are evening-type younger adults, who tend to show reliable effects of synchrony on measures of verbal memory (e.g., Fabbri et al., 2013; Intons-Peterson et al., 1999; May et al., 1993; Petros et al., 1990).

Older-neutral types failed to show a synchrony effect for immediate memory (LMI), but did show better performance on long-term memory (LMII) at midday than in the evening, and reliably less forgetting midday and in the morning than when tested in the evening. These data replicate findings of robust synchrony effects observed with older morning-types, who show better long-term verbal memory when tested in the morning relative to the evening (e.g., Hasher et al., 2005; Intons-Peterson et al., 1999; Lehmann et al., 2013; May et al., 1993), and suggest that long-term retention is best when neutral-type older adults are tested at their peak time of day.

We note that for some measures (e.g., Stroop effect, Logical Memory), the performance for neutral-type older adults tested in the morning did not differ reliably from that of neutral-type older adults tested midday. These findings could indicate that some of our neutral-type older adults were transitioning to morning-types

(as would be expected with age). The fact that the range of MEQ scores for neutral-type individuals is 42–59, and that the average MEQ score for older neutral-types was over 51, is consistent with this suggestion. Additionally, it may be the case that some of our neutral-type older adults experienced a broader window of optimal performance that included morning hours. Such a possibility would be consistent with the findings from neutral-type younger adults, who showed great flexibility in cognitive function over the day.

In addition to measures that are known to be susceptible to synchrony effects in evening-type younger adults and morning-type older adults, our investigation also included a battery of measures shown in other studies to be immune to synchrony, including access to general knowledge (high-cloze sentence completion rates, vocabulary scores, color naming) and processing speed (ordering in the Trail Making Part A, Letter Comparison Scores). Across all these measures, neither younger nor older neutral-types showed any differences in performance across the three testing times used in this study.[1] These findings align with those observed for both evening-type younger adults and morning-type older adults, who in numerous other studies show no effects of synchrony when task performance requires the use of familiar, highly-practiced responses or when dominant responses produce the correct answer (e.g., Borella et al., 2010; Hasher et al, 2002, 2005; May & Hasher, 1998; Song & Stoughton, 2000). The present data suggest that when individuals can rely on fairly automatic, well-learned knowledge, performance is fairly independent of circadian influences, regardless of age group, chronotype, or testing time.

In summary, our findings suggest that although younger neutral-type individuals show little effect of testing time on performance for an array of cognitive measures, older-neutral types demonstrate a pattern of performance that mirrors the pattern found for young and older adults with more extreme chronotypes. Specifically, performance is best for older neutral-types who are tested at their optimal time of day on tasks that require careful, analytic processing, the suppression of irrelevant information, and the retention of episodic information over a delay. The fact that older but not younger neutral-types demonstrate synchrony effects is consistent with data suggesting a significant impact of aging on the circadian arousal system (Schmidt et al., 2007), and findings of greater synchrony effects for morning-type older adults than evening-type younger adults (e.g., Borella et al., 2010; Lehmann et al., 2013; Li et al., 1998; May & Hasher, 1998; West et al., 2002). However, in the majority of those previous studies, evening-type younger adults demonstrated reliable albeit reduced synchrony effects, and by contrast neutral-type younger adults in the present study failed to show significant synchrony

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1   A power analysis using G*Power indicated that we had a power of 0.82 to detect medium (0.25) effect sizes, suggesting that the null effects observed for these variables do not reflect a lack of power.

effects for most tasks. Given that developmental data suggest that circadian arousal patterns shift from morningness in early childhood to eveningness in adolescence, and then back again to morningness with advancing age (e.g., Carskadon et al., 1993,1998; Czeisler et al., 1986; Ishihara et al., 1990; Kim et al., 2002; May & Hasher, 1998; Mecacci et al., 1986; Roenneberg et al., 2007), it is possible that the lack of a synchrony effect for neutral-type younger adults seen here might also reflect the fact that some, if not most, of the neutral-type younger adults are transitioning from evening to morning types. This transition from evening-type to morning-type may make circadian rhythms less consistent for younger neutral-types, resulting in a reduced likelihood that peak cognitive functioning will be tied to a specific time of day. Older neutral-types, by contrast, are more likely to be established as neutral-types rather than transitioning from evening-types to morning-types, and thus may show more robust synchrony effects.

With respect to research methods in general, these findings taken together with earlier work on morning-types suggest that tests of older adults will be biased against them to the degree that they are not tested at synchronous times of day, and this is especially so because more than 90% of older adults fall into the morning and neutral type categories. This assertion is likely important in the cognitive literatures, as well as in the neuropsych assessment and neuroimaging literatures, as recent studies suggest changes in brain activity and connectivity at peak versus off-peak times (Anderson et al., 2014; Marek et al., 2010).

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