Time-of-day matters in text learning and recall: Evening lessons are advantageous for adults with ADHD though not for typical peers

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A B S T R A C T
Motor skill (“how-to” knowledge) consolidation is enhanced when individuals with ADHD practice at evening. We tested, in adults with and without ADHD, whether evening lessons are advantageous for recalling texts (declarative memory). Participants (N = 40) listened to and read narrative texts in morning and evening lessons (crossover study). Recall was tested immediately post-lesson and 24 h and 8–10 days later. Recall tended to decrease over time but independently of ADHD status or the time-of-day of the lesson. Nevertheless, typical participants showed a morning advantage immediately post-lesson and in later recall, correlated with stronger morning chronotype. In contrast, participants with ADHD benefited more from evening lessons; nearer their preferred time-of-day. In adults with ADHD long-term declarative memory was no less durable than in typical adults after both morning and evening lessons, but a mismatch with their preferred diurnal “on-peak” time can lead to less effective engagement in learning during morning lessons.

1. Introduction

Students with Attention Deficit Hyperactivity Disorder (ADHD) often have difficulties in learning, acquiring and retaining, knowledge (Mayer et al., 2021). In the current study we addressed the possibility that some of these difficulties may reflect a time-of-day effect on learning (as was recently suggested in the context of skill learning; Korman et al., 2017). Young adults with ADHD tend to be more evening oriented (i.e., with a preference for performing cognitive and physical activities at evening hours) compared to their typical peers (Korman et al., 2020; Rybak et al., 2007; Voinescu et al., 2012). Thus, individuals with ADHD may face an added challenge given that much of academic and vocational education is a morning activity in institutions of learning and at work places.

ADHD is a common developmental disorder, affecting about 5% of school-age children but the symptoms frequently persist into adulthood as a full or incomplete syndrome (e.g., Goldman et al., 1998; Wender, 1998). Adults with ADHD have executive function deficits which include difficulties in response inhibition, maintaining sustained attention, and working memory (e.g., Barkley et al., 2001; Ehlis et al., 2008; Lambez et al., 2020). These deficits can result in learning and memory difficulties that affect the acquisition of skills, where practice is of essence (Fox et al., 2016; Korman et al., 2017; Skodzik et al., 2017). Whether adults with ADHD are impaired in learning and retaining new information is less clear (Advokat, 2010; Kaplan et al., 1998; Knouse et al., 2020; Skodzik et al., 2017).

The ability to express one’s full potential in the execution of a given task is dependent on diurnal changes in the levels of arousal and the person’s preference for performing such activities at a certain time of day – the individual’s chronotype (Horne & Östberg, 1976; Korman et al., 2019; Roenneberg & Merrow, 2016). About 40% of typical adults can be classified into one of the two extreme chronotypes: early morning preference (“larks”) and late evening preference (“owls”) (Roenneberg et al., 2003); 60% are intermediate types (Adan et al., 2012). However, more than 40% of adults with ADHD present a preference for conducting cognitive and physical tasks, and experience peak alertness, in the evening hours – a pattern exhibited in only 11% of age-matched healthy peers in the general population (Rybak et al., 2007; Voinescu et al., 2012). A clear advantage for a synchronicity between individuals’ chronotype (reflecting the time of day at which alertness and arousal

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peak in the diurnal cycle) and cognitive performance was found in multiple cognitive tasks, including memory performance (e.g., Facer-Childs et al., 2018; Hahn et al., 2012). Moreover, a mismatch between the time-of-day in which task performance abilities are tested and the person’s chronotype can bring to the fore many of the core symptoms of ADHD (Cassoff et al., 2012; Korman et al., 2020). Evening preference is also associated with a shorter sleep at night, and sleep debt may play a causal role in ADHD symptoms (Hennig et al., 2017; Korman et al., 2020; Rybak et al., 2007; van der Heijden et al., 2013). Also, arousal regulation (i.e., the dynamic process setting cortical activation propensity and the resulting variance in behavioral abilities) is often atypical in ADHD (Rybak et al., 2007; van der Heijden et al., 2013). Moreover, individuals with ADHD tend to be especially under aroused (i.e., present low alertness) during the morning hours (James et al., 2016; Korman et al., 2020; Zentall & Meyer, 1987).

An additional mechanism whereby the time-of-day may affect learning and memory processes is the interaction of the circadian cycles and neuronal plasticity processes (e.g., Iyer et al., 2014); one’s internal clock may play a role in gating (i.e., controlling the likelihood of) neuronal plasticity in the wake of a given experience (Albrecht, 2011). Typical and individual variability in circadian fluctuations of cortisol can modulate activity in the hippocampus, an important hub in the generation of memory (Maheu et al., 2005; Tsokanaki et al., 2016).

ADHD is characterized by a complex interaction among genetic and environmental factors (Korman et al., 2020; Srivastav et al., 2018; van der Meer et al., 2017). Polymorphisms in circadian control genes have been suggested to contribute to the polygenic risk for ADHD (van der Meer et al., 2017) and a link between these genes and genes related to ADHD risk has been established (Jones et al., 2016; Lane et al., 2016b). Thus, atypical diurnal cycles and consequently atypical time-of-day effects on performance are to be expected in persons with ADHD.

A recent study that addressed the acquisition and consolidation of a motor skill (non-declarative, procedural, memory) in young women with ADHD suggests that the time-of-day of the lesson – morning or evening – can be an important factor in attaining long-term skill (Korman et al., 2017). Motor memory consolidation processes were better engaged and the mastery of the new skill benefited when training was afforded at evening rather than at morning hours. Whether this holds true in relation to the engagement of mnemonic processes in learning situations wherein practice is not afforded, such as when reading a text or listening to a lecture, i.e., when presumably the declarative memory system is to be engaged, is less clear. Lectures and similar learning experiences affording exposure to new content and ideas are believed to engage the declarative memory system, because by this system a single event (episode) can suffice in triggering memory consolidation processes (e.g., Chun, 2000; Henke, 2016; Lukacs et al., 2017; Riedel & Blokland, 2015; Smith & Squire, 2018). In a study of time-of-day effects in relation to vocabulary learning, Gais et al. (2006) found a much higher rate of forgetting (in a test conducted overnight) after morning-learning compared to evening-learning. The authors suggested that participants may have been in different states of arousal during morning and evening lessons, or alternatively, affected by the amount of wake experience in the post-learning interval before the night’s sleep. The latter notion is better aligned with, for example, the Payne et al. (2012) results showing that the retention of a list of word-pairs following a 30-min interval was unaffected by the time-of-day of the lesson.

The rational underlying the current study was that individual differences in chronotype, specifically, morning versus evening chronotype, may constitute an important factor determining the ability to learn new texts or to consolidate them into long-term memory or both. Because, as a group, persons with ADHD tend to differ from their typical peers in terms of their pronounced evening preference, and given the significant time-of-day effects in learning and consolidating motor skills by persons with ADHD, that have been demonstrated in recent studies (Korman et al., 2017) we tested whether text (content) learning and memory would show different time-of-day effects in persons with ADHD compared to their typical peers.

Thus the aim of the current study was to test whether the time-of-day of the lesson will have a significant effect on the learning and retention of a narrative text (acquiring “what”, declarative knowledge) in persons with ADHD. The hypothesis was that evening lessons may lead to the better engagement of declarative long-term memory processes (though learning, encoding per se, will be unaffected) in persons with ADHD; in a manner similar to that previously described for skill learning in ADHD (e.g., Fox et al., 2016; Korman et al., 2017). We also tested the conjecture that typical young adult learners may not benefit from changing the time-of-day of the lesson – moving the lesson from morning to evening hours – because typical young adults, without ADHD, are more likely to have a morning preference (morning chronotype) and thus may be more alert and attentive during morning lessons compared to evening lessons.

2. Materials and methods

2.1. Participants

51 undergraduate students in an Israeli college (age 21–30 years; 25 females) volunteered to participate in the study (no monetary or academic compensation was offered to the participants). The participants were recruited through media platforms (Facebook pages, WhatsApp groups) for students in higher education. 40 participants met the inclusion criteria. Twenty-two participants (12 females) met the DSM-IV criteria for a diagnosis of ADHD, and 18 (9 females) were typical adults and served as a control (no-ADHD) group. The participants of the two groups did not differ in age or education (Table 1).

Inclusion criteria for the ADHD groups were as follows: (1) age between 20 and 35 years; (2) a formal diagnosis of ADHD/ADD from an authorized clinician, within 5 years of the current study; (3) a positive screening for ADHD based on the adult ADHD self-report scale (ASRS-v1.1, Adler et al., 2003; Kessler et al., 2007; see Table 1 and below for further details) – potential participants were instructed to refer in answering the questions of the ASRS-v to the 6-month period of time preceding the study; (4) a semi-structured interview (ADHD-RS; DuPaul et al., 1998) conducted to verify childhood onset of ADHD and persistence into adulthood; (5) no history of a developmental dyslexia; and (6) no specific pharmacological treatment for ADHD during the study period.

The typically developing participants with no ADHD (Typical) met no more than two of (the six) criteria of the ASRS-v1.1 screener (Table 1; four of the six criteria are required for positive screening). All participants were administered the full 18-item ASRS-v1.1 questionnaire. None of the Typical participants were previously suspected of (by family members or teachers) or tested for having ADHD. All participants completed the two experimental phases; there was no missing or corrupted data.

To rule out reading difficulties all participants were asked to read

Table 1

<table>
<thead>
<tr>
<th></th>
<th>ADHD</th>
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<td>SD</td>
<td>M</td>
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<tr>
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<td>18 items ASRS-v.1.1</td>
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<td>0.09</td>
<td>0.22</td>
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</tbody>
</table>

Note. ASRS-v.1.1 screener – % positive responses out of the 6 screener questions. 18 items ASRS-v.1.1 – % positive responses out of the 18 items questionnaire. Waking time – typical waking time during the month preceding the 1st day of the study. DS – digit span. *p < 0.05; ****p < 0.0001.

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aloud a list of Hebrew words as fast as they could for a test interval of 1 min (Shatil, 1997). Only participants who scored above 80 correct words per minute were recruited for the study. In addition, the Digit Span test was used to assess executive abilities (Wechsler, 1997). Participants were asked to repeat sequences of digits given by the examiner in the order they were heard (forward span) or in the reversed order (backward span). Both the maximum forward and the backward span scores were lower for the ADHD group compared to the Typical group (Table 1).

Participants reported at least 6 h of sleep per night, and no sleep/wake-cycle disruptions; they were asked to complete the PSQI sleep questionnaire; only participants with global scores below the cut-off (≤5) were included (Curcio et al., 2013). In addition, the participants were asked to complete the Horne–Östberg Morningness–Eveningness Questionnaire (MEQ) (Adan & Almirall, 1991) and instructed to keep a sleep diary for the night following the lesson (in both study phases). The participants were instructed not to drink caffeine-containing beverages during the experiment. The study protocol was approved by the ethics committee of the Wingate Academic College (107/19). All participants gave their written consent after being informed of the goals and nature of the study.

Group size was estimated using the G*power 3.1 software program. We planned a 2 × 3, cross-over design. Analysis of sample size given α = 0.05 and power of .80 with a medium effect size (f = 0.25) and a correlation among repeated measures of 0.5 indicated that a sample-size greater than 14 participants per group was required for the assessment of an interaction of Group*Time-of-day and to assess time-of-day effects within groups. Taking into account that the same participants were to be repeatedly tested in the same task (cross-over), the correlation among repeated measures were expected to be on the order of 0.7 (in fact, the correlations were above 0.8), indicating a group size of more than 14 as appropriate for examining an even smaller effect size (f = 0.20).

2.2. Study design

The experiment included two study phases (Fig. 1A). The order of the two study phases (i.e., morning lesson – evening lesson, evening lesson – morning lesson), was assigned randomly, but counter-balanced across participants (Fig. 1A). There was at least a two-week interval in-between the two lessons (phases).

Each study phase consisted of one lesson and three test sessions (mnemonic assessments). Mnemonic assessments were given immediately after the lesson (Test1), 24 h later (Test2), and 8–10 days post-lesson (Test3) (Fig. 1B). In Tests 1–3 the participants were asked to complete as many details (missing words) as they could recall from the text of the story that was presented in the lesson (cloze test). In the final assessment of each phase, the participants were asked immediately after completing the cloze test to recount the story with as many details as possible (free recall test) in writing (typing). All tests were audio and video recorded.

The two narrative texts were matched in length and in the number and type of details included in the text (explicit references to the time of day, time of year, persons’ names and age, the name of the place where the occurrences recounted in the story took place). The texts contained a story about an event in the form of a newspaper report (post office robbery, assault in hospital) and were fashioned in the form of texts used in the Rivermead Behavioral Memory Test (Wilson et al., 1989, 2008). A pilot study on young college students (N = 4) showed that the two narrative texts were equally well recalled in terms of gist and details (cloze test) immediately after a single presentation of the text (reading with no time restriction). In the study, the text was presented twice during the lesson; first in a pre-recorded audio form (through speakers, volume set according to each individual’s preference) and the second time through listening to the same pre-recorded audio file but with the text concurrently appearing as script on the computer screen.

The participants in each group, ADHD and Typical, were randomly

![Fig. 1. The study design. (A) The two arms and the two phases of the crossover study. (B) The time-course of each phase of the experiment.](image-url)
assigned into one of two phase-order groups (1 and 2, Fig. 1A), so that half the participants had a morning lesson in the first phase of the study (the lesson and subsequent memory tests affords at 7:00–10:30 a.m.) and the other half an evening lesson (lesson and subsequent memory tests afforded at 6:00–9:00 p.m.). All sessions were conducted online using the Zoom software (Zoom Video Communications Inc., 2019; San Jose, California, U.S. https://zoom.us/meetings).

The lessons took place in a quiet room in the participant’s home. The participants were instructed to move to the quiet room before starting the lesson; the microphone and video inputs from the participants’ end were ‘on’ throughout the session. The participants were told that they were taking part in a study concerning memory for text content and details. Before each presentation of the lesson’s material (story), the participants were encouraged to listen/read carefully and to try to remember as many details of the story as they can.

2.2.1. Mnemonic assessments

All assessments were in the form of a cloze test (Fig. 1B). In the cloze test, 34 words (items) were taken out of the original text and a dotted line was inserted to indicate the missing item. There were no more than 4 missing words (items to be completed) in each sentence; 2 missing words in a row occurred only when the item referred to a person’s or an institution’s name. The participants were asked to fill in as many “missing words” as they could recall, in order to “complete” the text to correspond to its form as presented in the lesson.

2.2.2. Free recall

In Test3 of each phase, after the cloze test was completed, participants were asked to reconstruct and type the story with as many details as possible (Fig. 1B). There were 3 measures used in the scoring of free recall; i. the number of items correctly recalled from the narrative text (specifically, from the 34 missing items of the cloze test), ii. the number of additional items (i.e., beyond the missing items of the cloze test) correctly recalled (based on Wilson et al., 1989); iii. the number of items incorrectly recalled (e.g., erroneous person and place names) and the number of false details (insertions, including details related to the text used in the previous study phase).

2.2.3. Alertness and mood

At the beginning and the end of each mnemonic assessment, participants were asked to report their own level of alertness using a visual analogue scale (VAS) (Chang et al., 2013) comprised of a horizontal line (with decade units marked); 0 and 100 corresponding to somnolent-sleepy to wide-awake, respectively. A second VAS was then provided for the participants to indicate their mood, with a similar linear scale of 0–100 (negative-low–positive-high, respectively).

Detailed descriptions of the assessment tools appear in Appendix 1.

3. Results

3.1. Performance in the cloze test

The number of items that were correctly recalled in the cloze tests in each of the assessment time-points of each study phase was calculated. To test for differences in recall between the groups (ADHD, Typical) and for time-of-day effects, we ran a three-way repeated measures general linear model based analysis of variance (rm-Anova) with the 3 assessment time-points and the 2 lesson times (Time-of-day: Morning, Evening) as within-subject factors and group as a between-subjects factor.

Overall, there was no significant difference in recall rates after Morning lessons as compared to Evening lessons (i.e., no significant effect of the time-of-day of the lesson) [F(1,38) = 0.624, p = 0.434, η² = 0.016]. Irrespective of the ADHD status (group) there was a significant Time-point effect, with a decline in the correct recall rates in successive assessment time-points after the lesson [F(2,76) = 34.759, p = 0.001, η² = 0.478] (Fig. 2). However, there was a significant difference between the recall rates of the 2 groups [F(1,38) = 6.420, p = 0.016, η² = 0.145], with the participants of the Typical groups outperforming their peers with ADHD (Fig. 2). There was, moreover, a significant interaction of Time-of-day × Groups [F(1,38) = 32.086, p < 0.001, η² = 0.458], because the time-of-day of the lesson had a differential effect on subsequent recall performance in the two groups. (See Appendices – Table A1 for additional analyses; the interaction of Time-of-day × Time-point or Time-of-day × Group were not significant).

The differential effect of the time-of-day of the lesson was explored by analyzing cloze test recall rates in each of the two groups separately. In the ADHD group, there was an overall advantage (across the 3 time-points of the experiment) for Evening lessons over Morning lessons [F(1,21) = 28.686, p < 0.001, η² = 0.579] (Fig. 2). However, irrespective of the time-of-day of the lesson, although the loss was small, the number of items that were correctly recalled in Test2 and Test3 decreased significantly compared to the number of items that were recalled correctly immediately after the lesson (Test1) [F(2,42) = 0.718, p < 0.001, η² = 0.049]. Recall after an evening lesson showed an advantage vis-a-vis performance after a morning lesson already in Test1 (65% vs. 54% correct items, p = 0.001) and in again in Test2 (63% vs. 49%, p < 0.001) and Test3 (59%, vs. 45%, p < 0.001). There was, however, no significant interaction of Time-of-day × Test-point (F(2,42) = 1.435, p = 0.250, η² = 0.064); recall attrition was not affected by time-of-day.

In participants of the Typical group recall rates were significantly better, across the 3 time-points, after a morning lesson than after an evening lesson [F(1,17) = 8.675, p = 0.009, η² = 0.338] (Fig. 2). As in the ADHD group, the participants of the Typical group showed that irrespective of the time-of-day of the lesson, the number of items that were correctly recalled in Test2 and Test3 decreased compared to the number of items that were recalled correctly in Test1 [F(2,34) = 14.744, p < 0.001, η² = 0.464]. There was no significant interaction of Time-of-day × Test-point (F(2,34) = 0.119, p = 0.888, η² = 0.007).

The differential effects of the time-of-day of the lesson on the ability of participants in the two groups to subsequently recall the particulars of the lesson were robust. In fact, participants with ADHD showed as good a recall after an evening lesson as their typical peers in the same condition (Typicals recalled 65%, 62% and 58%, Tests 1–3, respectively) (Fig. 2). However, morning lessons were advantageous for the Typical group at all time-points compared to their achievements after an evening lesson (75% vs. 65%, p = 0.003; 71% vs. 62%, p = 0.009; 68% vs. 58%, p = 0.005; Test1-3, respectively) (Fig. 2). We also looked at the proportion of participants in each group (ADHD, Typical) who showed a reduction in cloze test scores across the time-interval between Test1 and Test3 (8–10 days) to test for the possibility that more individuals from the ADHD group were able to retain the details of an evening lesson compared to a morning lesson. Fig. 3
presents the proportion of participants who retained or even improved their scores in the cloze test over the 8–10 day interval compared to their peers whose performance deteriorated. More participants with ADHD were able to retain (or improve) their scores after an evening lesson compared to after a morning lesson (7/22, 4/22, respectively), but the difference was not significant \[ \chi^2(1) = 1.091, p = 0.296, c = 0.157 \] (Fig. 3A). The proportion of Typical individuals with good retention was unaffected by whether the lesson was afforded in the morning or at evening hours (Fig. 3B).

### 3.2. Performance in the free recall test

A two-way analysis of variance with repeated measures (2 × 2) was used to test for differences in free recall scores, obtained at Test3 of each study phase, between the two groups (ADHD, Typical) after morning and evening lessons. There was a significant interaction of Time-of-day × Groups [F(1,38) = 12.767, p = 0.001, \( \eta^2 = 0.251 \)] in the recall of the missing items (Fig. 4A). Post-hoc comparisons showed that when the lesson was learned in the evening, the ADHD participants recalled a significantly higher number of correct items than when the lesson was given in the morning, \[ t(21) = -3.775, p = 0.001, d = 0.80 \] (Fig. 4A). Typical participants recalled on average more missing items after a morning than after an evening lesson, but the difference was not significant \[ t(17) = 1.581, p = 0.132, d = 0.37 \] (Fig. 4A).

A similar analysis of the number of items recalled beyond (other than) the cloze test items showed that although, overall, the Typical group did better than the ADHD group \[ F(1,38) = 7.457, p = 0.009, \eta^2 = 0.164 \], there was no significant effect of the time-of-day of the lesson and no significant interaction of Time-of-day × Groups (Appendices – Table A.2B) (Fig. 4B).

The number of items incorrectly recalled, including the number of false details provided in the free recall tests, did not differ in the two groups; there was no significant effect of the time-of-day of the lesson (Appendices – Table A.2C) (Fig. 4C).

### 3.3. Alertness and mood across the experiment

To test for differences in alertness and mood across the experiment, we ran a four-way analysis of variance with repeated measures (2 × 3 × 2 × 2) on the alertness and mood VAS scores; group assignment (ADHD, Typical) was considered a between-subjects factor. The time-of-day of the lesson (morning, evening) and the three sessions, with, in each session, two assessments (start and end of the session), were included as within-subject factors.

#### 3.3.1. Alertness self-assessment scores

There was a significant effect of the time-of-day of the lesson \[ F (1,38) = 4.484, p = 0.041, \eta^2 = 0.106 \], with participants, overall, reporting higher levels of alertness in the evening (Appendices – Fig. 1A). The difference in alertness levels was mainly the result of the lower morning alertness scores obtained from the ADHD group; there was a trend for a significant interaction of Time-of-day × Groups \[ F (1,38) = 3.872, p = 0.055, \eta^2 = 0.092 \] (Appendices – Table A.2D).
The effects of the time-of-day of the lesson and tests were quite consistent across the three assessment sessions of the experiment (Appendices – Table A.3). There was, however, a significant difference between the start and end of the session, with all participants reporting an increase in their alertness levels across the test sessions [F(1,38) = 22.034, p < 0.001, η² = 0.367]; a significant interaction of Time-of-day × Within-session-assessment [F(1,38) = 11.733, p = 0.001, η² = 0.236] indicated larger increases in alertness, within-session, in morning sessions. No other interactions were significant (Appendices – Table A.3).

3.3.2. Mood self-assessment scores

There was a trend for a significant effect of the time-of-day of the lesson [F(1,38) = 3.253, p = 0.079, η² = 0.079] with participants, overall, reporting a more positive mood in the evening (Appendices – Fig. 1B); there was no significant interaction of Time-of-day × Groups (Appendices – Table A.3). As in their reports on alertness, participants – irrespective of group – reported an increase in their positive mood levels across the assessment sessions [F(1,38) = 6.584, p = 0.014, η² = 0.148] (Appendices – Table A.3).

3.4. Chronotype

The average MEQ scores for the two groups differed; more participants in the ADHD group reported lower MEQ scores, corresponding to an evening preference, compared to their Typical group peers (13/22 vs. 2/18 of the ADHD and Typical participants, respectively) [t(38) = 4.870, p < 0.001, d = 1.55] (Table 2).

In the combined sample (ADHD and Typical) higher MEQ scores (corresponding to morning preference) were associated with better Test1 cloze test scores (R² = 0.604) in the morning lesson/tests phase. No correlation was found in the evening lesson/tests phase in the combined sample or in the two groups separately. (Additional data and analyses, Appendix 4).

4. Discussion

The results of the current study show that although, overall, the participants with ADHD were outperformed by their Typical peers in terms of the ability to recall details and items from texts taught in the lessons, there was a clear time-of-day effect; the difficulty incurred by the participants with ADHD was to learn the text in morning lessons, but the two groups were equally adept in learning and recalling the texts if learning was afforded in the evening. Moreover, the effect of the time-of-day of the lesson – morning or evening – on the ability to recall the content of a lesson was contingent on the participants’ ADHD status. The participants with ADHD showed a clear advantage for cloze and free recall after evening lessons compared to morning lessons, both immediately and 8–10 days after the lessons. In the Typical group, morning lessons resulted in significantly better recall rates in the cloze tests, compared to after evening lessons.

4.1. A difficulty in learning at morning hours but not a memory deficit

Importantly, the advantage for evening lessons in persons with ADHD (as in the morning advantage in Typical persons) was clear already in the immediate post-lesson assessments, and was then maintained across the subsequent recall assessments. Thus, the relative disadvantage of a morning lesson for participants with ADHD appeared in the learning phase. Moreover, the results clearly showed that the time-of-day of the lesson did not affect the ability of the learners to generate long-term memory and subsequently to recall the content and details of the text learned in the lesson. Given that the immediate post-learning recall test is predominantly a measure of encoding efficiency (e.g., Travis et al., 2014), i.e., a measure of what or how much was learned in the course of the lesson, the current results suggest that the relative disadvantage inherent in a morning lesson for participants with ADHD (compared to an evening lesson and compared to typical peers receiving a morning lesson) may lay in a reduced likelihood of attending to (Alloway & Pasqualonghi, 2011; Burden & Mitchell, 2005; Lambe et al., 2020) and encoding (Kim et al., 2014; Voinescu et al., 2012) the content and details of texts presented at morning hours. We therefore propose that, as a group, participants with ADHD had their main difficulty in learning the material (i.e., in the “online” encoding of the content of the lesson). However, subsequent to that, the rate of attrition-stabilization in recall performance was unaffected by the time-of-day of the lesson (note that in each study phase, all of the subsequent recall tests took place at the same time-of-day as the lesson) or by the participants’ ADHD status.

Learning and memory are related but are not the product of the same set of biological processes (e.g., Dudai, Karni, & Born, 2015). A clear dissociation between time-of-day effects on long-term memory consolidation but not on learning, albeit in a different pattern from the one we find in the current study, has been described (e.g., Korman et al., 2017). The time-of-day of the lesson was found to effect performance after memory consolidation but not before these processes were afforded time to be completed, i.e., the time-of-day of the learning session affected memory without affecting learning within the session per se (Fox et al., 2016; Korman et al., 2017). For text learning, as shown by the results of the current study, the time-of-day of the lesson affected online encoding but had no significant effect on the time-course of subsequent retention. Thus, the evidence does not support a time-of-day effect on offline declarative memory processing, contrary to what was found in studies addressing motor skill learning (procedural memory) (Fox et al., 2016; Korman et al., 2017) and, the data do not support the notion of a deficit in long-term memory for texts in persons with ADHD.

4.2. Differential time-of-day effects in declarative and procedural memory

The current results pertaining to the learning of texts in a lesson that affords only a very limited opportunity for rehearsal and presumably engages declarative memory processes to achieve long-term retention (Gais et al., 2006; Payne et al., 2012), do not support the notion – raised in recent studies of skill acquisition in ADHD in respect to procedural, “how-to” knowledge, memory – that declarative long-term memory mechanisms are atypical in persons with ADHD; there may not be a simple symmetry between the two memory systems in terms of their susceptibility to ADHD. We propose that in persons with ADHD the learning of texts, and possibly in other instances of learning that do not afford practice and repeated rehearsal, when declarative memory is potentially engaged the effects of the time-of-day of the lesson may predominantly affect the learning itself (encoding), while long-term memory as reflected in subsequent recall rates is unaffected.

It has been proposed that memory consolidation processes affecting the stability and long-term retention of verbal information can be triggered during the lesson, and then continued after the lesson has terminated; the affordance of a post-learning sleep is often a factor in such
post-learning processes and the generation of long-term memory (see Davis & Gaskell, 2009; Ellenbogen, Hulbert, et al., 2006; Gais & Born, 2004; Gais et al., 2006; Korman et al., 2015). Sleep was available much earlier after evening lessons as compared to the morning lessons in the current study. However, typical participants as a group showed a clear advantage for morning lessons, indicating that post-lesson sleep was not a critical factor in later recall performance. In participants with ADHD, the advantage of evening lessons was already apparent immediately after the lesson (i.e., before sleep was afforded), and the attrition-stabilization of recall rates subsequent to the immediate post-learning assessment was unaffected by the time-of-day of the lesson; i.e., unaffected by the earlier availability of sleep after an evening lesson.

A similar line of argument makes post-lesson interference effects an unlikely mechanism for explaining the time-of-day effects that we found in the Typical and ADHD groups. Interference effects, specifically the retroactive effects of events that the learner experiences during the daytime after a lesson, have been shown to significantly modulate the ability to consolidate and retain the knowledge gained in the lesson, whether the knowledge afforded in the lesson was procedural (Fox et al., 2017; Hesse et al., 2016; Korman et al., 2007) or declarative (Ellenbogen, Payne, & Stickgold, 2006; Robertson, 2012) in nature. More interference from the learners’ daytime experience was expected after a morning lesson (e.g., Davis & Gaskell, 2009; Korman et al., 2015); however, the current results show that text recall was not significantly affected by the nature of the post-learning interval (before the night’s sleep) in either group, Typical or ADHD.

4.3. Chronotype effects

The current results suggest that an important factor mediating the differential effect of the time-of-day of the lesson on the learning of narrative texts, in persons with and without ADHD, is the learner’s chronotype – the preference of morning or evening hours for accomplishing tasks and performing activities. Correlation analyses showed that irrespective of their ADHD status, participants showed a “synchronicity effect” (e.g., Correa et al., 2020; Krishnan & Lyons, 2015), so that higher morning preference (higher MEQ scores) tended to be associated with better recall of the content of the morning lesson immediately after the lesson. The correlations were even stronger in Text3, 8–10 days after the lesson. We propose, therefore, that the difficulties that many young adults with ADHD experience when attending morning lessons may relate, at least in part, to their evening-oriented daily preference and presumably to an increased likelihood of experiencing a suboptimal arousal state during the morning (Korman et al., 2019, 2020). Decreased arousal in the morning may lead to morning lessons affording less than optimal learning experiences – less engagement while learning the details of a narrative text, as well as, possibly, less engagement of the practice-triggered memory consolidation process in the acquisition of skill (Fox et al., 2016). On the other hand, for evening persons, and persons with ADHD specifically, evening lessons may afford learning experiences at the time-of-day when arousal and cognitive abilities are at their highest.

We recorded the participants’ self-assessments of their level of alertness (vigilance) as well as their mood, during the morning and evening lessons and during the subsequent sessions when recall was re-tested. Overall, participants with ADHD tended to be more alert in the evening, in line with the higher proportion of more evening-oriented individuals in this group. In the Typical group, there was a trend for increased alertness during the morning lessons compared to evening lessons, but these very same participants tended to report better (higher) mood at evening sessions. Improved mood (positive affect) during evening hours, regardless of ADHD status, is a recognized phenomenon (Murray, 2007). Also, irrespective of the time-of-day, both groups reported an increase in mood levels across the lessons and the recall test sessions, suggesting that the lessons and tests were, overall and quite consistently, a positive experience.

Previous studies have established that the time-of-day preference correlates with typical students’ accomplishments; evening-type persons exhibited poorer performance in school and university, where typically students are required to engage in morning activities (e.g., Tonetti et al., 2015). It was suggested that evening preference was more of a problem in schoolchildren and especially in adolescents, compared to university students, because the latter have more control over their learning schedules (Tonetti et al., 2015). There is an increase in the proportion of “late chronotypes” among typically developing adolescents, but while persons without ADHD switch towards morning preference at around the age of 20 (Roenneberg et al., 2004), adults with childhood-onset ADHD frequently remain life-long “night owls” (Googan & McGowan, 2017).

The current results do not support a simple notion of a declarative long-term memory deficit in ADHD (Advokat, 2010; Skodzik et al., 2017; Valera et al., 2005). Rather, the current results clearly indicate that, in the long-term - beyond the immediate post-lesson test - the ability of persons with ADHD to retain the content and details of a newly learnt text is not necessarily inferior compared to the retention levels achieved by typical persons in identical learning conditions. Also, a simple notion of an inherent problem with working memory in young adults with ADHD (e.g., Alderson et al., 2013) raises the problem of why persons with ADHD do as well as their typical peers in evening lessons. The current results suggest an alternative framework – that working memory deficits, if present, may not be constitutional in persons with ADHD but rather may reflect performance at a suboptimal time-of-day. The current results are therefore in line with the circadian mismatch hypothesis, which suggests that cognitive deficits may stem from the dissonance between the internal biological time and the clock time (time-of-day) (Hervey et al., 2004). Taking into account the circadian preference of the trainees in the scheduling of lessons, in both typical adults (Bennett et al., 2008; Hahn et al., 2012; Lara et al., 2014) and young adults with ADHD (Fox et al., 2016; Korman et al., 2017, 2020), may be beneficial for enhancing learning and as a result long-term retention.

The results of this small sample size, exploratory study, suggest atypical time-of-day effects in young adults with ADHD compared their typical peers. The study sample, however, constituted a very specific group, undergraduate college students; it remains open how and to what degree chronotype differences affect learning and memory in persons with ADHD from other age-groups, academic abilities and occupations. Also, the current results open the question of whether and to what degree chronotype differences affect learning and memory in individuals taking stimulant medication or in persons with ADHD with learning disabilities as co-morbid states (Advokat, 2010; Lonergan et al., 2019; Gnanavel et al., 2019). The current study was undertaken during the COVID-19 pandemic, circumstances that may impact ADHD symptomatology and daily behaviors such as exposure to daylight and level of physical activity (Korpa et al., 2021; Sibley et al., 2021). Whether and to what degree factors other than the mismatch between chronotype and the time-of-day of the learning experience contribute to making morning lessons difficult for persons with ADHD are questions open for future explorations. Future studies should also address the possibility that interventions such as memory reactivation during the evening or before sleep may be effective for enhancing the long-term retention of morning lessons, as seen in studies on sleep-related reactivation protocols (Hu et al., 2021; Schouten et al., 2022).

Altogether, the current findings suggest that learning outcomes, in lessons and learning experiences that presumably rely on the engagement of declarative memory, may improve for many young adults with ADHD who are off stimulant medications, by scheduling lessons for evening hours. The current results do not support the notion that long-term memory for texts is potentially less robust in persons with ADHD than in typical peers; however, text learning and, indirectly, subsequent text recall, may benefit, in young adults with and without ADHD, from
decreasing the mismatch between chronotype and the time-of-day of the learning experiences.

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CRediT authorship contribution statement

Mahmood Sindiani: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing. Maria Korman: Formal analysis, Writing – review & editing. Avi Karni: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Appendix A. Supplementary data

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References


