Tehran University of Medical Sciences

IJOH International Journal of Occupational Hygiene
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eISSN: 2008-5435

Iranian Occupational Health Association IOHA

ORIGINAL ARTICLE

Temporal Variations and Interrelationship of Planning Ability and Working Memory in College Students

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Received 2024-09-30; Revised 2024-11-12; Accepted 2024-11-18

This paper is available on-line at *http://ijoh.tums.ac.ir*

ABSTRACT

Background: Executive cognitive functions are essential for functioning in dynamic environments. Moreover, they are directly influenced by work schedules and tend to decline over the course of a shift, resulting in an increased number of errors. Given that educational activities typically commence at fixed times, this study aimed to evaluate planning ability and working memory (WM) with temporal variations in college students.

Methods: Forty-three participants were randomly selected from the occupational health and ergonomics students. WM and planning ability were assessed using the Wechsler Memory Scale (WMS) and Tower of London (TOL) test, respectively. The data were evaluated using SPSS version 16.0.

Results: The mean scores of the TOL index were 31.46 and 31.42 in the morning and afternoon, respectively. The auditory working memory index was 7.54 and 7.7, whereas the visual working memory (VWM) index was 9.12 and 9.0 in the morning and afternoon, respectively. Planning ability and VWM were higher in the morning than in the afternoon. There was a relatively good correlation between median thinking times/the WMS index and the time of tests ($p \leq 0.05$).

Conclusion: Interestingly, the results showed no correlation between planning ability and WMS. Additionally, based on the findings, it is recommended to add courses requiring problem-solving and high-level focus to the morning curriculum.

KEYWORDS: *Planning ability, Tower of London, Working memory, Wechsler memory, College students, Training program*

INTRODUCTION

Executive functioning (EF) is critical during cognitive evaluations of clinical and nonclinical populations. However, executive processes are inherently complex and difficult to assess [1]. These processes, which collectively encompass working memory (WM), cognitive flexibility/set-shifting, and inhibition, are essential for functioning in dynamic environments such as school and university [2]. They also have a well-

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established relationship with psychological factors such as depression, anxiety, and personality [3]. Major depression and anxiety disorders are known to negatively influence cognitive performance; greater cognitive decline has been associated with anxiety disorders [4]. Prior research has also shown that sleep deprivation impairs cognition and performance [5], including working memory [6]. Educational start times for students in the 14–24 age range are linked to chronic, irrecoverable sleep loss of more than 2 hours each day [7]. Roenneberg et al. reported that changes in circadian timing, when conflicting with early school and university start times, result in increased sleep deprivation with age [8]. Therefore, sleep loss can be associated with an increased risk of poorer attention, performance, and memory consolidation [9]. Some studies have reported beneficial effects of exercise on cognition. Chang Yu et al. found that the intensity of resistance exercises—where muscle contraction is opposed by force to increase strength or endurance—could facilitate executive functions in middle-aged adults [10].

Planning ability is a fundamental and ubiquitous cognitive function [11]. The term "planning ability" describes the capacity to cognitively model solution possibilities and assess the consequences of an action before it is performed [12]. Demographic characteristics influence planning ability and problem-solving. Rainville et al. reported that age can affect planning ability [13]. Motivational beliefs, such as self-efficacy, are additional factors that could enhance the efficiency of planning ability through focused effort [14].

Some studies have also reported that planning ability is related to WM [15, 16]. WM is defined as the online preservation and manipulation of information for a few seconds. It involves a central executive, phonological loop, and visual performance [17]. Lin et al. reported that acute exercise could benefit WM at a macro-neural level [18]. Executive functions in active WM may strongly contribute to predicting mathematical planning ability skills. For example, individuals with difficulty in planning ability have shown weaker WM for control processes than individuals with good planning abilities [19, 20]. In one study in 2012, it was reported that reading comprehension and planning ability, as cognitive skills, were improved by promoting WM [20].

Since education and work typically begin at fixed times, institutions have historically sought to adapt individuals to organizational structures. However, aligning organizational schedules with the needs of those who study and work within them can enhance overall time efficiency [21]. Several studies confirm that cognitive performance diminishes during a shift, leading to an increased number of errors and accidents [22, 23]. The scholarly literature suggests that cognitive performance is directly related to the time of work. In one study, Evans et al. determined ranges of start times that optimized cognitive functioning for undergraduates. They suggested that start times around noon or a couple of hours later were optimal for all students [24].

Unfortunately, no studies were found on the relationship between WM, planning ability, and temporal variations in college students. A better understanding of temporal variations in cognitive functions would significantly enhance our knowledge of how to optimize training and learning programs for college students. Thus, the objective of this study was to assess the interplay between planning ability and working memory (WM), focusing on their relationship with temporal variations among college students.

MATERIALS AND METHODS

This study was designed and conducted at an ergonomics laboratory at the University of Medical Sciences. It should be noted that a sample size of 30 is considered a valid minimum according to the central limit theorem. Based on previous studies, sample sizes ranging from 40 to 1000 have been examined for similar tests. Considering that our target group consisted of approximately 80 individuals, 43 participants were selected, similar to the Chang et al. study [25]. Thus, forty-three participants were randomly selected from the occupational health and ergonomics students. All students had normal color vision and no auditory or motor disabilities. Additionally, on the exam days, students had classes both in the morning and in the afternoon. All participants gave their informed consent to take part in the study.

At first, a questionnaire was completed by the participants. The questionnaire was a

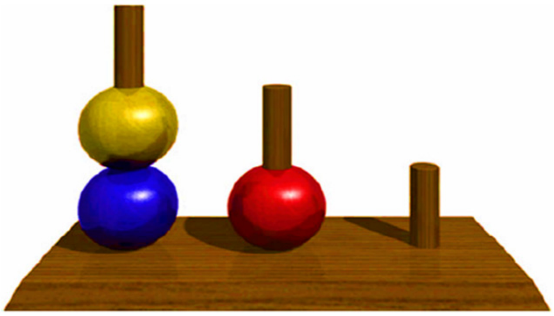

Figure 1. The physical layout of the computerized tower configurations in the TOL-F mimicking a realistic representation of the original wooden tower and balls

research instrument consisting of demographic characteristics, including age, gender, marital status, level of education, course of education, daily intake of milk, dormitory residence, and regular daily exercise. In the field of cognitive function, a number of psychometric instruments have been developed and are assessed through computer-based simulations [26]. In this study, WM and planning ability were measured by the Wechsler Memory Scale (WMS) and the Tower of London (TOL) test, respectively, using computerized software. The tests were administered at two distinct times. The training program or curriculum at the Department of Occupational Health is scheduled from 8:00 AM to 12:00 PM and from 2:00 PM to 6:00 PM. Between the morning and afternoon sessions, there is a 2-hour rest and lunch break. Accordingly, planning ability and WM were measured based on the class schedule. Since learning may affect test responses, each test (both planning ability and WM) was administered with a seven-day delay. Finally, the data were evaluated using SPSS version 16.0.

The Tower of London (TOL) task test

In 1982, in a study of planning deficits demonstrated by patients with frontal lobe lesions, Shallice proposed and used an alternative to the classic Tower of Hanoi (TOH) task. He dubbed the proposed replacement the TOL. The TOL task is now frequently used to investigate planning ability in both clinical and nonclinical studies [27]. The TOL test is a task used to measure planning ability and problem-solving [28]. It is considered a nonverbal task that does not require complex verbal abilities, except for understanding instructions. Since it is a new task for all participants, they do not possess subroutines for solving problems—particularly complex ones. In general, several studies have shown that the TOL is a good representative for assessing planning ability [29].

The TOL was administered on a PC consisting of three rods of different heights, on which three differently colored balls were placed. The minimum number of moves for the current trial was indicated on the left side of the start state. Each trial was limited to one minute, as shown in Fig. 1. In the TOL program, the goal state is presented on one side of the screen, and to solve the problem, the respondent must convert the start state into the goal state. To move a ball from the start state configuration, the respondent must first select it by clicking on it. Then, by clicking on the desired position, the selected ball can be moved to that location.

Subjects were asked to transform the start state to match the goal state while following three rules: (a) only one ball could be moved at a time; (b) a ball could not be moved if another ball was already on top of it; and (c) the tallest peg on the left could hold three balls, the middle peg two balls, and the smallest peg on the right only one ball. The computer program did not allow any moves that violated these rules.

Twelve patterns were used in the TOL-F test to evaluate problem-solving capabilities. The required time for the TOL test was approximately 16 minutes. The test's reliability and validity were reported as ≥ 0.71 and 0.61, respectively. Interpretations of the mean scores and percentages of the TOL-F test are presented in Table 1 [30].

The Wechsler Memory Scale (WMS)

The Wechsler Memory Scale (WMS) is one of the most widely used memory batteries to

Table 1. Interpretation of percentages for planning ability

Interpretation of percentages	Percentage of planning ability
Below average	16≥
From below average to average	16-24
Average	25-75
From average to above average	76-84
Above average	84≤

Table 2. The demographic characteristics

N= 43		
Variables	**Frequency and mean (S.D)**	**Percentage (%)**
Age in years (mean, SD)	22.65(2.8)	52.67
Gender (M/F)	16/27	37.2/62.8
Marital states (M /S)	3/40	6.97/93.03
Course of education (Under G /G)	37/6	86.04/13.96
Daily intake of milk(Yes/No)	2/41	4.65/95.35
Living in dormitory(Yes/No)	28/15	65.11/43.89
Regular exercise activity in day(Yes/No)	11/32	25.58/47.42

Note: F/M stands for Female/Male, M/S for Married / Single and Under G /G for Undergraduate / Graduate

assess various memory functions [31]. Kent et al. suggested that WMS is a reliable measure for working memory (WM) assessment [32]. It is commonly used in memory evaluations [33]. A fourth edition of the WMS (WMS-IV) was published in 2009 [34]. WMS-IV includes subtests designed to assess verbal/auditory and visual memory, as well as WM. Standardized scores were obtained using age-matched normative data from the WMS-IV manual for individuals aged 16–90. Regarding its psychometric properties, reliability coefficients were reported between 0.93–0.96, and the test–retest reliability for the index scores ranged from 0.79–0.82 [34].

The WMS-IV test was used to measure visual and auditory memory in both immediate and forward conditions. Subtest scores were presented as scaled scores (i.e., M = 10; SD = 3). The memory span for WMS-IV subtest scores was also reported as a scaled score, with a mean of 9 ± 3. The total time required for the WMS-IV test was approximately 15 minutes.

Data analysis

Firstly, the Kolmogorov–Smirnov test was used to determine the data distribution. The data were analyzed using SPSS version 16.0. Descriptive statistics were used to assess characteristics including age, gender, marital status, level of education, course of education, daily intake of milk, dormitory residence, regular daily exercise, and the TOL and WMS-IV indices. Differences in demographic variables and cognitive tests (TOL and WMS-IV) were tested using ANOVA or chi-square tests. The t-test was also used to determine the differences between the means of the two time periods (morning and afternoon) for the WMS-IV and TOL indices. The correlation between TOL-F and WMS-IV indices was assessed using the Pearson correlation test. The alpha level for all analyses was set at 0.05.

RESULTS

The results of the Kolmogorov–Smirnov test indicated that the data distribution was normal (p-value > 0.05). Table 2 presents the means of the demographic characteristics, including age, gender, marital status, level of education, course of education, daily intake of milk, dormitory residence, and regular daily exercise. The mean age of the participants was 22.65 ± 2.8 years. Most of the students were female (62.79%), lived in dormitories (65.12%), and were undergraduates (86.05%).

The mean scores of the TOL-F index and variables depending on planning ability are shown in Table 3. The average TOL-F index in the morning and afternoon *was* 31.46 and 31.42, respectively. Therefore, planning ability for the college

Table 3. The mean scores of the TOL-F index and comparison of the test results between morning and afternoon

TOL Test variables	mean		
	Morning	afternoon	p-value
Planning ability	31.46	31.42	.431
Number of error	10.84	10.42	.624
Median thinking time	133.35	114.82	.000
Median testing time	161.09	154.84	.166
Median total testing time	295.60	269.65	.198

Table 4. The association between the demographic characteristics and results of the tests

	P-value						
Variables	Age	Gender	marital status	course of education	daily intake of milk	daily regular exercise	living in dormitory
Planning ability	0.805	0.49	0.17	0.426	0.576	0.763	0.691
Visual Memory Index	0.565	0.657	0.164	0.439	0.928	0.927	0.273
Auditory Memory Index	0.278	0.389	0.608	0.477	0.578	0.183	0.322

Table 5. The mean scores of the WMS-IV index and comparison of the test results between morning and afternoon

WMS-IV Test variables	mean		
	Morning	afternoon	p-value
Auditory Memory Index	7.54	7.72	.000
Auditory digit span forward	7.54	7.72	.000
Visual Memory Index	9.12	9.00	.001
Visual digit span forward	9.12	9.00	.001

students was average. The results of *the* T-test analysis suggested that there was no significant difference between the two time periods in terms of the planning ability index (P = 0.43). The mean variables of TOL-F were higher in the morning than in the afternoon. As planning ability increased, the number of errors, thinking time, testing time, and total testing time also increased (Table 3). ANOVA and chi-square did not reveal a significant relationship between the demographic characteristics and the TOL-F index as the dependent *variable* (Table 4).

The results of WMS-IV are shown in Table 5. The t-test analysis suggested that there was a significant difference between WMS-IV indices in the two time periods. The mean of the Auditory Memory Index (AMI) was lower in the morning (7.54) than in the afternoon (7.72). In contrast, the Visual Memory Index was higher in the morning (9.12) than in the afternoon (9.00). The mean of the Visual Memory Index was observed to be higher than the mean of the AMI. The results of ANOVA and chi-square showed no significant association between the demographic characteristics and the WMS-IV index and also revealed that the difference between auditory reaction and visual memory was not significant (Table 4).

The results of the Pearson correlation showed no correlation between planning ability and WMS-IV. However, there was a moderate correlation between visual memory and auditory memory (Pearson correlation = 0.496, P-value = 0.001 in the afternoon; Pearson correlation = 0.437, P-value = 0.003 in the morning). Moreover, the Pearson correlation revealed a moderate correlation between visual memory and auditory memory across the two time periods (Pearson correlation = 0.507, P = 0.001 for visual memory in the morning; Pearson correlation = 0.542, P = 0.000 for auditory memory in the afternoon).

DISCUSSION

According to the results of this study, the planning ability and visual WM indices were higher in the morning, whereas the AMI was higher in the afternoon. Overall, the AMI mean was lower than the visual WM mean. Moreover, time was observed as an effective factor on planning ability and WM. Several studies have confirmed the effects of different factors on planning ability and WM. For example, Ph. Zimme et al. reported that exhaustive exercise could alter thinking times in the TOL. They showed that median thinking times were reduced thirty minutes after the completion of the physical intervention. Interestingly, these shifts appeared to diminish with increasing time. Moreover, their study showed that a higher lactate rate resulting from physical activity was associated with less impaired cognitive performance [35]. In the current study, although planning ability and WM were reduced with increasing time—similar to the previously mentioned studies—exercise did not affect planning ability or WM.

As mentioned, no literature was found on the relationship between WM, planning ability, and daily periods. However, the results of several studies on the relationship between reaction time as a cognitive performance and time of day indicated that time affected reaction time [22, 23]. Research on drivers showed that decreased perception and anticipation, incorrect reactions, and reduced selective attention caused driver errors and train accidents over time [23]. Fletcher et al. reported that the reaction time and number of errors committed during a vigilance task increased during the shift [36, 37]. Interestingly, in this study, planning ability and WM increased in the morning, but variables dependent on them—such as median thinking time and number of errors—decreased in the afternoon. Although it can be concluded that time is an important and effective factor on cognitive and executive functions, the type of work is another influential factor affecting planning ability and WM. Naturally, the degree of fatigue and sleepiness is observed to be higher among drivers than among students.

Johnson's study on the effect of visual and auditory reaction and memorization-based tasks on temporal performance indicated that the temporal difference between auditory reaction and visual memory was only marginally significant. However, participants responded to auditory-based tasks in a longer time compared to visual tasks [38]. Sharma et al. reported that the mean reaction time was shorter for visual memory than for auditory memory [39]. The obtained results confirm that visual memory is better than auditory memory and that there is a significant difference between auditory and visual memory. In this study, the visual and auditory memory scores were average and approximately similar.

McCabe et al. reported a strong correlation between WM capacity and executive function [40]. Swanson et al. found that the effectiveness of generative strategies training among children at risk for math difficulties was directly dependent on the level of WM capacity [41]. Moreover, Steinberg et al. indicated the importance of WM capacity in performance on the TOL [42]. In this study, among most participants, an increase in WM was accompanied by an elevation in planning ability. However, there was an extremely weak correlation between planning ability and WM. Although the planning ability required to solve problems primarily results from typical operations carried out by basic WM mechanisms—responsible for the maintenance, retrieval, transformation, and control of information across a broad range of intellectual tasks—it appears that planning ability can be modified and enhanced through intervention programs such as training.

Albert et al. reported that planning ability, as assessed by the TOL test, improved in late adolescence and early adulthood. They also found a relationship between age and WM capacity [42]. However, the results of this study showed no significant correlation between age, planning ability, and WM capacity. This study involved college students as research participants, all of whom were approximately the same age (mean = 22.65; SD = 2.8). Therefore, it can be inferred that age might influence planning ability and WM if the distribution of age groups in the population were more diverse.

Previous studies have shown the positive effects of acute resistance exercise on executive function [43]. Y.-K. Chang et al. illustrated that acute resistance exercise could facilitate planning-related executive functions in adults aged 40–65 years [10]. In contrast, Pontifex et al. examined two types of aerobic exercise and resistance exercise on cognition. They demonstrated that WM performance changed after aerobic exercise, while no differences were observed following acute resistance exercise [44]. Li et al. reported that acute exercise significantly influenced WM [18]. The obtained results showed that daily regular exercise was ineffective on the TOL and WMS. It is implied that the type and timing of

exercises may influence cognitive function.
Rahmani et al. studied the effects of daily milk consumption among school students. The results of their study showed that the Wechsler Intelligence Scale value was higher in daily consumers of milk [45]. In contrast, Tyngleong et al. indicated that consuming milk had no significant effect on either short-term memory or sustained attention [46]. In the current study, no significant effect was found between daily milk consumption and the planning ability and WM indices. Naturally, the existing relationship between these variables is influenced by the sample size. Therefore, intervention studies are required to directly measure the effects of daily milk consumption.

The findings of the current study showed that planning ability and WM were higher in the morning. Evans et al. reported that start times around noon or a couple of hours later (after 11:00 a.m. or 12:00 noon) were beneficial for all students, as they demonstrated the best cognitive functioning during these hours. Nevertheless, no single start time was identified as optimal, allowing students to begin their working day at a time best suited to their individual preferences [24]. Moreover, the Centers for Disease Control and Prevention, the American Academy of Pediatrics, and the American Medical Association recommend that middle and high schools should open no earlier than 8:30 a.m. [47, 48]. Accordingly, it may be concluded that the best time for cognitive functioning is before 12:00 p.m., when planning ability and WM increase. However, due to the increased number of errors and longer median thinking time during this period, this conclusion cannot be considered definitive.

There were limitations in this study, including a small sample size and a focus on academic performance. As mentioned previously, due to the variety of cognitive evaluation tests, only the TOL and Wechsler tests were used in this study. Thus, it is unclear whether the current results can be generalized to other sets of tests. It is imperative to use a broader range of cognitive functioning assessments to determine whether the results would replicate. In addition, this was a cross-sectional study, and the effects of different factors on planning ability and WM should be measured in intervention studies. For example, some research has indicated that the acute exercise effect lasts 30–52 minutes after the exercise session ends [49]; however, Barella et al. failed to confirm this finding [50]. Therefore, such studies should be further developed.

CONCLUSION

Planning ability and visual WM were higher in the morning than in the afternoon. Hence, time can be considered an effective factor influencing planning ability and WM, although its estimated impact was relatively minor. Therefore, it is recommended that courses requiring problem-solving and high-level concentration be scheduled in the morning within the Department of Occupational Health curriculum. The results of this study may be useful in developing appropriate learning processes and curricula. However, further investigation is necessary to clarify the factors that effectively influence cognitive and executive performance.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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