The Link between Mind-wandering and Performance in a Sustained Attention to Response Test in Adults with Attention-deficit/Hyperactivity Disorder Symptoms

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Abstract

Objectives: The symptoms of attention-deficit/hyperactivity disorder (ADHD) have been positively documented to be correlated with unintentional mind-wandering (MW) in the literature. In this study, we intended to explore the link between the types of MW and the attention laboratory performance in adults with ADHD symptoms. **Methods:** We recruited 24 adult patients with ADHD and 30 controls: (a) to receive a semi-structured psychiatric interview for ADHD and other diagnoses, (b) to complete questionnaires about adult ADHD symptoms and other psychiatric symptoms, (c) to receive intelligence assessment, (d) to have thought probes during a Sustained Attention to Response Task (SART), and (e) to be assessed with the MW: Spontaneous Scale (WM-S). **Results:** Adult patients with ADHD symptoms showed a more impulsive SART response style (increased commission errors and fast response speed) and unintentional MW. Increased unintentional MW was associated with reduced task performance. A positive association existed between MW-S scores and unintentional MW during the SART. **Conclusion:** Spontaneous MW may be significant impairment in adults with ADHD. Different measurements of MW had the associated and consistent findings measured by cognitive laboratory task with thought probe or WM-S measurement.

Key words: adult attention-deficit/hyperactivity disorder, commission errors, task performance, thought probes
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Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a neurodevelopmental disorder characterized by age-inappropriate inattention (IA), hyperactivity, and impulsivity [1]. The latest reported prevalence of ADHD in children is 9.5% in the United States of America [2], and 8.7% in Taiwan [3]. The symptoms of ADHD commonly persist during adolescence [4] and adulthood [5], especially IA [5, 6]. Adults with ADHD have deficits in vigilance during tasks designed to assess attention [7, 8], with more errors and higher reaction time variability (RTV) [7, 9, 10] related to their attentional lapses [11, 12]. Recently, mind-wandering (MW) has been described as the subjective psychological experience of these attentional lapses in patients with ADHD [13, 14]. Because of the link to fluctuating performance, attentional lapses are one of the key cognitive deficits in patients with ADHD [14, 15].

MW has been conceptualized as shifting an individual's attention and thoughts away from external current sources or ongoing tasks to unrelated internal thoughts and feelings [16, 17]. Two main types have been identified, i.e., deliberate and spontaneous MW [16, 18, 19]. Deliberate MW reflects self-generated internal thoughts unguided by the current task and may be related to low motivation [19] or strategic and

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intentional attention allocation [18, 20]. Spontaneous MW reflects an involuntary attentional shift to task-unrelated thoughts, which impacts executive functions and attentional control [18]. Investigators in several studies suggested that intuitive MW is related to ADHD symptoms [21, 22], and reflects dysfunctional connectivity between the default mode network (DMN) and the executive control network in the brain [13, 23].

In previous studies, investigators have used various methods to measure MW [16, 24, 25]. The instruments to measure the MW trait, are the MW Scale [26, 27] and the Mind Excessively Wandering Scale [25]. A widely used laboratory measure of MW is to embed the thought probes within a cognitive task, measuring the MW while the participant performs the laboratory task [20, 28]. MW is a universal human experience, with studies showing that adults spend almost one-third to half of their waking hours engaging in self-generated thoughts irrelevant to the stimuli present in their situation or context [29]. But investigators in many studies showed that adults with ADHD have been reported to have a more significant amount of spontaneous MW both in their daily life [24, 30] and during laboratory cognitive tasks [30, 31]. Furthermore, the degree of spontaneous MW is positively associated with the severity of ADHD symptoms [16, 19]. Thus, excessive MW is a common co-occurring feature in adults with ADHD [24, 30]. However, few studies have examined the direct link between periods of MW and performance on attentional tasks in the ADHD population [16].

MW is surprisingly detrimental to task performance [17]. For example, using the Sustained Attention to Response Task (SART), several studies showed that participants have faster reaction times (RTs) and more commission errors in task-unrelated thoughts than those of nontask-unrelated thoughts involving mind disengagement [32]. Recently, Franklin et al. have shown an association between poor SART performance and MW in adult patients with heightened ADHD symptoms [16]. But none of the investigators in those previous studies have directly examined whether the state of MW is detrimental to task performance in adults with ADHD.

Heightened variability in task performance is a characteristic marker of attentional lapses in ADHD [9, 15]. Moment-to-moment fluctuations in task performance are strongly related to MW, especially spontaneous MW. Adult patients with ADHD are expected to show worse task performance during periods of MW. But no studies have yet been reported to examine whether the ADHD and control groups have different task performance when both groups report a task-focused state. Whether they display similar attentional performance under these circumstances remains unknown. In this study, we intended to explore (a) whether subjective MW measurements and laboratory task performance have convergent findings, and (b) whether the associations exist between task performance and MW, measured both through trait scales and through thought probes embedded within the SART.

Methods

Study participants

We recruited 58 adult patients, aged 20–40 years, through advertisements in the outpatient clinic of Linkou Chang Gung Memorial Hospital and public places on the campus of Chang Gung University, Taoyuan, Taiwan. We asked those who were interested in our study, to report their clinical ADHD symptoms through e-mail. Then, they were screened through a telephone interview conducted by a senior clinical psychologist (SLHG, corresponding author). Twenty-six participants were classified as having ADHD symptomatology (see below), and 32 participants were classified as typically developing controls (TDCs) without ADHD symptoms, according to the modified adult version of the ADHD supplement of the Chinese version of the Kiddie-Schedule for Affective Disorders and Schizophrenia – Epidemiological Version (K-SADS-E) used for current and childhood diagnosis of ADHD [33, 34]. The classification into groups was based on the K-SADS-E interviews and the participants' reports. The diagnostic coding was categorized as "definite ADHD" (reaching full DSM-IV diagnostic criteria), "probable ADHD" (more than half but less than all of the DSM-IV symptom criteria), "possible ADHD" (some symptoms but no impairments), and "no diagnosis" (no symptoms). Participants receiving the "definite ADHD" or "probable ADHD" code were assigned to the "ADHD symptom" group and participants receiving the "possible ADHD" or "no diagnosis" codes were assigned to the TDC group.

Excluded from this study were those participants with (a) estimated IQ < 70; (b) having any neurological disorders, such as seizures or brain injury; or (c) having substance use, or with lifetime diagnoses of learning disability, autism spectrum disorder, schizophrenia, bipolar disorder, major depression, or anxiety spectrum disorder. Excluded were four participants – one having an estimated IQ < 70 and three having extremely high mood disorder symptoms in the Health, Personality, and Habit test (HPH) [35]. Finally, our study included 24 adults with ADHD symptoms and 30 TDC adults.

Measurements

The Chinese version of the Adult ADHD Self-Report Scale (the ASRS in Chinese, ASRS-C)

The ASRS has 18 items with a five-point Likert scale and was developed in conjunction with the revision of the World Health Organization Composite International Diagnostic Interview (CIDI) [36]. The contents of the ASRS were generated based on ADHD symptoms typically expressed among adults with ADHD and included two subscales, IA and hyperactivity-impulsivity (HI), each of which has nine items. The ASRS in Chinese was developed through a two-way translation by three child psychiatrists and a professional bilingual translator [37] and has good reliability (Cronbach's α = 0.83–0.91). Studies have shown that the ASRS-C has been proven to be a valid clinical tool for screening adults with ADHD [38].

Sustained Attention to Response Task mind-wandering task

The MW task is a computerized task that uses the random version of the SART paradigm written in E-Prime 2.0 (Psychology Software Tools, Pittsburgh, Pennsylvania, USA) to measure MW indirectly. The SART is a go/no-go task in which the digits 1–9 are presented in a pseudorandom order, and the participant is asked to press the space bar immediately when any digit appears on the screen (go trials), except for the digit "3" (no-go trials) [39]. As shown in Figure 1, a digit was presented for 250 ms, then a mask was presented for 900 ms, followed by the start of the subsequent trial. A block consisted of nine trials (pseudorandom presentation of the digits 1–9), with a probe question presented after every five blocks. Participants responded to the probe through selecting the condition that best described them at that point in the task: (a) focused on the task ("I was focusing on the task demanding," (b) intentional MW ("I was thinking the unrelated events deliberately," and (c) unintentional MW ("I was thinking the unrelated events spontaneously." In our study, we had 900 trials in 100 blocks and 20 probes in the SART (Figure 1).

The dependent variables were omission error rates, commission error rates, hit mean RT, and hit RT standard deviation (RTSD). Because the RT distribution was positively skewed, the DISTRIB toolbox for MATLAB was used to fit three parameters (mu [μ], sigma [ρ], and tau [τ]) to the ex-Gaussian distribution [40] to characterize the SART RTs. The frequency of the categorical MW (intentional/unintentional) and task-focused responses were also recorded.

The previous nine trials of each probe represent the performance of the state of intentional MW, unintentional WM, and task focusing. The dependent variables of the performance were the error rate (commission errors, omission errors), RT, and RTSD for the comparisons among groups.

The Chinese version of the Mind-Wandering: Spontaneous Scale (MW-S in Chinese, MW-S-C)

The MW-S is a self-administered scale with four items to measure the spontaneous mind-wandering in daily life [26] and includes the items "I find my thoughts wandering spontaneously," "When I mind wander my thoughts tend to be pulled from topic to topic," "It feels like I do not have control over when my mind wanders," and "I mind-wander even when I'm supposed to be doing something else." The items were translated into traditional Chinese with culturally relevant colloquial expressions by a board-certificated psychologist in Taiwan (the third author) with permission granted by the original author. The confirmatory factor analysis index indicates an acceptable fit (X^2/df = 5.47, RMSEA = 0.14, CFI = 0.97, TLI = 0.90, and SRMR = 0.03). Cronbach's alpha coefficient is 0.85 (unpublished data of CF Hsu, 2021, personal communication).

Procedures

The institutional review board at Chang Gung Medical Foundation approved this study (IRB protocol number = 201900092B0C601 and date of approval = March 25, 2019), with the need of obtaining written informed consent from the participants.

All participants completed the short form of the Wechsler Adult Intelligence Scale-Fourth Edition (WAIS-IV), including the subtests of information, symbol search, matrix reasoning, and digit span. The results of WAIS-IV were used to exclude participants whose estimated Full-Scale IQ was lower than 70. All participants were interviewed independently by individual well-trained interviewers using the Chinese K-SADS-E. Among the 24 adults with ADHD symptoms, 4 participants had a clinical diagnosis of ADHD diagnosed before the study, and they had been treated for ADHD (methylphenidate). Adults with ADHD were asked to halt medication for at least 24 h before the tests. Each participant received the MW task and completed the Chinese ASRS, HPH, and the Chinese MW-S self-reports. The whole test set lasted 1.5 h.

Statistical analysis

The two comparison groups were adults with ADHD symptomatology and TDC adults. Detailed demographic comparisons are expressed as frequencies, percentages, and Chi-square statistics for categorical variables, and means ± standard deviation and *t*-test statistics for continuous variables.

Since normal distribution was not confirmed for several variables, the nonparametric Mann–Whitney test was used to compare the main effect of the group (ADHD symptomatology vs. TDC). We calculated the effect size for all variables ($r = Z/\sqrt{N}$) [41] that evaluate the strength of a statistical

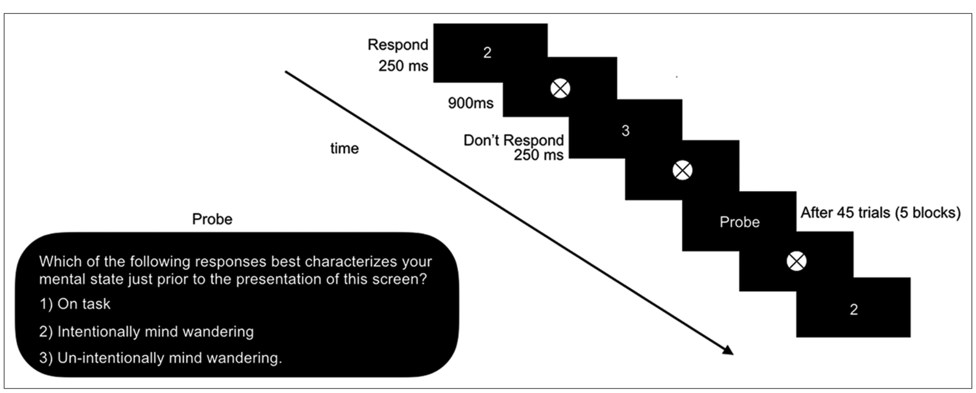

Figure 1. The mind-wandering task on the Sustained Attention to Response Task.

claim (small: 0.1-0.3, medium: 0.3-0.5, and large: ≧0.5). Next, Spearman's rank correlation coefficients were calculated to describe the associations between the Chinese MW-S scores, the frequency of MW in SART, and ADHD symptoms.

Statistical analyses were conducted using Statistical Analytic System version 9.4 (SAS Institute Inc., Cary, North Carolina, USA). The differences between the groups were considered significant if *p*-values were smaller than 0.05.

Results

No significant difference existed between the two groups in age, gender ratio, or estimated Full-Scale IQ. But compared with the TDC group, adults with ADHD symptoms had significantly higher IA ($p < 0.001$) and HI ($p < 0.001$) scores, as measured using the ASRS, and significantly higher spontaneous MW scores ($p < 0.001$) as measured using the Chinese MW-S (Table 1).

For the thought probes in the SART, adults with ADHD symptoms had a significantly higher frequency of unintentional MW responses ($p < 0.01$) and a lower frequency of task-focused responses than the TDC group ($p < 0.01$). In SART performance, adults with ADHD symptoms had significantly faster values of mu ($p < 0.05$) (Figure 2), and significantly more commission errors ($p = 0.001$) and omission errors ($p < 0.05$) than the TDC group (Table 2).

On the links between the thought-probe responses (MW and task-focusing) and attention performance assessed by SART, a group difference in attention performance was observed only during unintentional MW (Table 3). Adults with ADHD symptoms had a significantly higher rate of commission errors than controls when unintentional MW was reported ($p < 0.05$).

The Pearson correlation analyses revealed that MW-S scores were significantly and positively associated with the frequency of unintentional MW responses to the SART probes ($p < 0.001$) and significantly and negatively associated with the frequency of task-focused responses ($p < 0.001$). The MW-S scores were also significantly and positively associated with the rate of commission errors in the SART ($p < 0.05$). We also found that the severity of ADHD symptoms was significantly and positively associated with the MW-S score and with the frequency of unintentional MW responses to the SART probes ($p < 0.01$) and significantly and negatively associated with task-focused responses to the SART probes ($p < 0.001$). ADHD symptoms were also significantly and positively associated with the rate of commission errors in the SART ($p < 0.001$) (Table 4).

Table 1. Characteristics of study participants

	Adults with ADHD symptoms ($n = 24$)	TDC ($n = 30$)	t/χ^2
Age, years, mean ± SD	23.25 ± 2.74	23.53 ± 4.03	0.29
Male sex, *n* (%)	7 (29.2)	9 (30.0)	0.01
Estimated FSIQ	106.29 ± 11.93	106.03 ± 11.50	0.08
Total score	44.48 ± 8.64	23.10 ± 8.20	9.11***
Inattention	24.30 ± 5.55	14.03 ± 4.65	7.26***
Hyperactivity/impulsivity	20.17 ± 4.97	9.07 ± 5.15	7.85***
MW-S score	15.33 ± 3.10	8.70 ± 3.60	7.15***

***$p < 0.001$

ADHD, attention-deficit/hyperactivity disorder; TDC, typically developing control; FSIQ, Full-Scale IQ score; MW-S, Wind-wandering-Spontaneous Scale; SD, standard deviation

Discussion

To our best knowledge, the current study is the first report to examine the link between periods of subjective MW/task-focusing and performance in a SART attention task in adults with ADHD symptoms. In line with previous studies, adults with ADHD symptoms have faster RTs and more commission errors in the SART, indicating deficits in inhibitory control [42]. Furthermore, adults with ADHD symptoms have been reported to have more unintentional MW responses and fewer task-focused responses to the thought probes in the SART. The important finding was that task performance in adults with ADHD symptoms was significantly and detrimentally impacted

Table 2. Thought-probe responses and Sustained Attention to Response Task performance

	Adults with ADHD symptoms ($n = 24$)	TDC ($n = 30$)	Mann-Whitney U	*Z*	Effect size
Thought-probe responses					
Unintentional MW	12.00	7.50	209.50	−2.63**	−0.36
Intentional MW	0.50	0.50	345.00	0.78	0.11
Task-focused	6.00	11.00	195.50	−2.87**	−0.39
SART performance					
Commission errors	18.00	7.50	168.00	−3.35***	−0.46
Omission errors	36.00	13.50	238.00	−2.13*	−0.29
RT, ms	288.20	328.28	251.00	−1.90	−0.26
RTSD, ms	94.34	84.21	276.00	−1.46	−0.20
Mu, ms	220.67	257.24	239.00	−2.11*	−0.29
Sigma, ms	55.69	54.89	349.00	−0.19	−0.03
Tau, ms	68.05	58.39	247.00	−1.92	−0.26

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

Values expressed as median

SART, Sustained Attention to Response Task; ADHD, attention-deficit/hyperactivity disorder; TDC, typically developing control; MW: mind-wandering; RT, reaction time; RTSD, RT standardized deviation; ms, millisecond

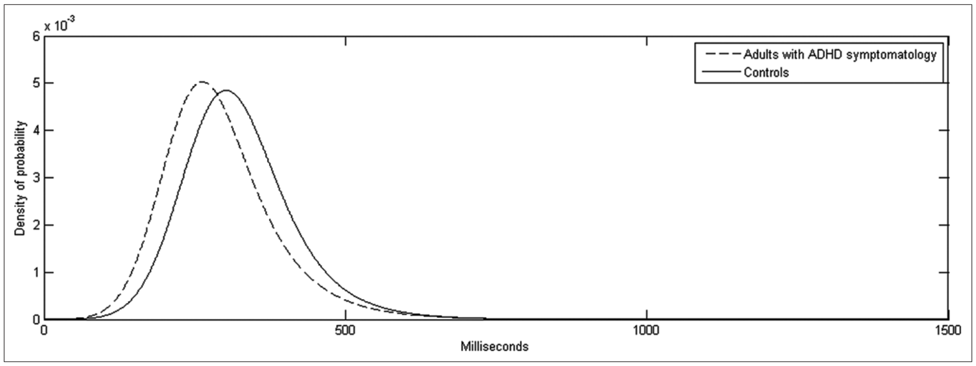

Figure 2. The ex-Gaussian distribution of reaction times on the Sustained Attention to Response Task for adults with ADHD symptoms and typically developing adult controls. ADHD, attention-deficit/hyperactivity disorder.

Table 3. Performance§ during the intentional/unintentional mind-wandering and task-focused periods

	Adult with ADHD symptoms	TD	Mann-Whitney U	Z	Effect size
Unintentional MW					
Commission errors	2.00	1.00	165.500	−3.21***	−0.44
Omission errors	5.00	3.00	237.00	−1.83	−0.25
RT, ms	283.00	307.00	271.50	−1.18	−0.16
RTSD, ms	92.50	81.50	234.50	−1.86	−0.25
Intentional MW					
Commission errors	1.00	0.00	54.00	−1.92	−0.26
Omission errors	0.00	0.00	87.00	−0.16	−0.02
RT, ms	270.00	304.00	52.00	−1.85	−0.25
RTSD, ms	70.00	83.00	60.00	−1.46	−0.20
Task-focused					
Commission errors	0.50	0.00	249.50	−1.15	−0.16
Omission errors	2.00	1.00	248.50	−1.05	−0.14
RT, ms	287.57	320.02	247.00	−1.05	−0.14
RTSD, ms	86.87	81.83	237.00	−1.25	−0.17

***$p < 0.001$

§Values expressed as median

ADHD, attention-deficit/hyperactivity disorder; TD, typical development; MW, mind-wandering; RT, reaction time; RTSD, RT standardized deviation; ms, milliseconds

Table 4. Associations between the mind-wandering in different mind-wandering measurements, attention-deficit/hyperactivity disorder symptoms, and Sustained Attention to Response Task performance

	MW-S	ADHD symptoms	Intentional MW	Unintentional MW	Task-focused	Commission errors	Omission errors	RT	RTSD
MW-S	1.00								
ADHD symptoms	0.72***	1.00							
Intentional MW	0.12	0.11	1.00						
Unintentional MW	0.59***	0.35**	−0.04	1.00					
Task-focused	−0.60***	−0.43***	−0.48***	−0.82**	1.00				
Commission errors	0.32*	0.49***	0.10	0.30*	−0.37**	1.00			
Omission errors	0.21	0.24	0.06	0.22	−0.24	0.68**	1.00		
RT	−0.22	−0.29	−0.18	−0.144	0.20	−0.29*	0.19	1.00	
RTSD	0.13	−0.06	0.09	0.12	−0.23	0.46**	0.52***	0.37**	1.00

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

ADHD, attention-deficit/hyperactivity disorder; MW, mind-wandering; MW-S, MW-Spontaneous Scale; RT, reaction time; RTSD, RT standardized deviation

during the periods of unintentional MW (as indicated by the heightened commission errors) ($p < 0.05$) but was not affected during the periods when participants reported being focused on the task (Table 3). We also found that the level of real-world MW (Table 4) (measured by the Chinese MW-S score) was significantly and positively associated with unintentional MW and commission errors in the SART ($p < 0.001$). Thus, different MW measurements produced consistent results in our study.

Finally, consistent with previous studies, we found that ADHD symptoms were positively associated with MW ($p < 0.001$), whether measured as a trait by the MW-S or as unintentional MW in the laboratory task (Table 4).

As shown in several studies [43, 44], adults with ADHD have deficits in performance on vigilance tasks. Heightened response errors and RTV are associated with deferred effort allocation, which is needed to sustain accuracy and consistent responses in vigilance tasks [43]. In the current study (Table 2), adults with ADHD symptoms had significantly faster response speeds than TDC adults ($p < 0.05$), whether assessed as the mu values in the ex-Gaussian. Meanwhile, their heightened commission errors indicate an impulsive response pattern [43]. But in our study (Table 2), adults with ADHD symptoms did not show significantly heightened RTV, whether measured as the RTSD or as the sigma and tau values in the ex-Gaussian analyses. This unusual finding may be due to the number of pauses in the task for the thought probes: halting the procedure may affect RTV in the vigilance task [45]. Despite this unusual finding in our study (Table 2), adults with ADHD symptoms still show attentional deficits in the SART, with an impulsive response pattern [43].

In the current study (Table 2), adults with ADHD symptoms showed significantly more unintentional MW responses to the SART probes than TDC adults ($p < 0.01$) but a similar level of intentional MW responses. Meanwhile, adults with ADHD symptomatology also had significantly higher scores for the spontaneous MW trait measured using the Chinese MW-S ($p < 0.001$). These results are consistent with previous studies showing that spontaneous MW is associated with ADHD symptoms, whether measured as a trait [24] or as performance on a laboratory task [24, 45]. Furthermore, we found evidence (Table 3) that only the periods of spontaneous MW were significantly associated with deficits in attentional performance on the SART in adults with ADHD symptomatology ($p < 0.05$). No difference existed in task performance during periods of intentional MW or when focused on the task. These results can be considered in line with the DMN interference hypothesis of spontaneous MW in ADHD [13], in which changes in the DMN are associated with spontaneous MW and interfere with task performance [13]. But any such interpretation must remain tentative because we did not monitor DMN activity through brain imaging in this study. Van Son et al. used electroencephalographic techniques to examine the associations between MW and frontal slow-wave theta activity (4–7 Hz), fast-wave beta activity (13–30 Hz), or the theta/beta ratio (TBR) during a breath-counting task [46]. They found that healthy adult participants had remarkably higher frontal TBR during MW episodes [46]. This finding shows the value of the temporal analytic approach because elucidating the associations between neural processing and MW is vital during specific MW episodes, especially for spontaneous MW in ADHD [32].

Another substantial finding (Table 4) of our study was the consistency of the results from the MW-S trait-based measurement and the SART probes. Furthermore, we showed that both the MW-S trait-based measurements and the probe-based measurements of spontaneous MW were significantly and positively associated with commission errors in the SART ($p < 0.05$). Based on this finding, we suggest that spontaneous MW is a stable subjective experience or behavioral habit that can manifest anywhere and is positively associated with deficits in task performance [13, 24].

In the current study (Table 4), we found that significant correlations existed between the severity of ADHD symptoms and the MW-S scores ($p < 0.001$), as well as that significantly higher frequency existed in unintentional MW, measured through thought probes in the SART ($p < 0.01$). This finding provides clear evidence that spontaneous MW may be a remarkable feature of ADHD symptomatology [16, 25]. The severity of ADHD symptoms was also significantly positively correlated with commission errors in the SART ($p < 0.001$). This finding is consistent with previous findings that ADHD symptoms are associated with deficits in inhibitory control [43].

Study limitations

Although the current study has many strengths, the readers are warned not to overinterpret the study findings because it has four methodological limitations:

- The clinical implications of the study for adults with ADHD are limited by the small sample size and by the fact that most of the participants were not clinically referred.
- We used only the MW-S scale and not the conscious MW (MW-D) scale; this makes it difficult to assess how the findings from an overall MW trait measurement (MW-S and MW-D) would converge with those from the SART thought probes.
- No difference existed in the gender ratio between the two groups in our study. Our study included more female participants than male ones. This finding is in contrast to the almost 1:1 male/female ratio in adults with ADHD [47]. This may limit the clinical implications of our study for adults with ADHD.
- Although the current study was found a link between spontaneous MW and deficits in attentional performance, we did not monitor neural activity related to the thought probes in the SART, so interpretation of the results should remain conservative. Future studies should consider addressing this limitation.

Summary

The present study provides preliminary evidence to support the hypothesis that spontaneous MW but not in a task-focused state could impact the vigilance in adults with ADHD symptoms. Hence, preventing the spontaneous MW can benefit adults with ADHD in attentional performance and functioning in daily life. Franklin et al. showed that awareness of MW decreases detrimental MW in ADHD symptomatology [16]. This finding suggests that training in recognizing and controlling MW – such as using external cues/reminders [16] or mindfulness training [48] – may benefit adults with ADHD to manage their attention problems.

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Conflicts of Interests

Susan Shur-Fen Gau, an editorial board member at *Taiwanese Journal of Psychiatry* (Taipei), had no role in the peer review process of or decision to publish this article. The other authors decalared no conflicts of interest in writing this paper.

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