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Mind-wandering and sleepiness in adults with attention-deficit/hyperactivity disorder

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ABSTRACT

Sleepiness and mind-wandering are frequently experienced by patients with attention-deficit/hyperactivity disorder (ADHD), without ever having been jointly explored. We aimed to investigate the co-occurrence of these two phenomena in ADHD adults.

Drug-free ADHD adults ($n = 25$) and healthy controls ($n = 28$) underwent an online experience sampling of mind-wandering episodes and subjective sleepiness. Participants completed self-reported measures of mind-wandering and sleepiness in daily life.

Higher trait of mind-wandering was observed in ADHD patients compared to controls. On the whole sample, self-reported mind-wandering propensity was strongly associated with the severity of inattentive, impulsive and hyperactive symptoms. During the probes, patients reported more frequent episodes of mind-wandering and mind-blanking, and higher sleepiness. Their mind-wandering episodes were less intentional and belonged less frequently to a structured succession of thoughts. In both groups, mind-wandering and mind-blanking were associated with higher sleepiness. On the SART, patients were less accurate than controls.

We provide first initial evidence for higher propensity of mind-wandering and mind-blanking using experience sampling in patients with formal ADHD diagnosis. This propensity was associated with sleepiness without negatively impacting attention performances. Mind-wandering and sleepiness have common determinants potentially involved in ADHD pathophysiology. Correlates of mind-blanking in ADHD adults remain to be characterized.

1. Introduction

Mind-wandering is generally defined as a shift in content of thought away from an ongoing task to thoughts that are both task-unrelated and stimulus-independent (Smallwood and Schooler, 2006, 2015; Stawarczyk et al., 2011). Mind-wandering represents about 30–50% of our mental activity during the day (Killingsworth and Gilbert, 2010; Kane et al., 2007). It can be measured using a range of direct and indirect measures. These include rating scale state and trait measures, experience sampling in daily life, experience sampling during experimental paradigms, and brain imagery (Smallwood and Schooler, 2015). It is commonly accepted that mind-wandering leads in a disengagement of attention from the environment reducing sensitivity to external stimuli (Smallwood et al., 2008). This perceptual decoupling is generally associated with deleterious consequences on ongoing performances during various cognitive performances from simple detection tasks to more complex activities such reading comprehension and driving (for a meta-analysis, see Randall et al., 2014 ;Smallwood and Schooler, 2015; Smallwood et al., 2008; Burdett et al., 2019). Mind-wandering emergence is also closely linked to deployment of executive control (McVay and Kane, 2009, 2010). In particular, it has been documented that executive control is engaged to suppress mind-wandering under challenging conditions in favor of task performing. When the environment is nondemanding, the executive control is less required, which increases mind-wandering phenomenon. This is known as the context regulation hypothesis (Smallwood and Andrews-Hanna, 2013). More recently, some authors have stressed the importance of distinguishing between intentional (deliberate) and unintentional (spontaneous) types

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of mind-wandering (Seli et al., 2013, 2013). When this distinction is taken into account, unintentional mind-wandering propensity increases in the difficult tasks relative to the easy tasks (Seli et al., 2016). In this context, spontaneous mind-wandering has been interpreted as the result of a failure of executive control leading to an internal distractibility.

Attention-deficit/hyperactivity disorder (ADHD) is a neurodevelopmental disorder characterized by inappropriate levels of inattention, impulsivity, and hyperactivity (American Psychiatric Association, 2013). It is now recognized that in 40–60% of cases, symptoms persist into adulthood and old age (e.g., Biederman, 2005; Adler et al., 2009; Culpepper and Mattingly, 2010; Volkow and Swanson, 2013). The prevalence of ADHD is estimated at 3% in the French population (Caci et al., 2014). The nature of the cognitive impairments associated with adult ADHD are very similar to those described in children (e.g. Schoechlin and Engel, 2005). These admittedly heterogeneous impairments particularly concern the sustained attention and the executive functioning (e.g. Barkley, 1997; Mostert et al., 2015; Fuermaier et al., 2014).

Several studies have investigated links between mind-wandering and ADHD symptoms severity in non-clinical samples consisting only of college students (for review, Lanier et al., 2019). By using thought probes during a sustained attention task, some of these studies have documented that mind-wandering was related with higher level of ADHD symptoms with detrimental effect on performances. This relationship has been also described when mind-wandering trait was assessed on a self-reported measure. More recently, research has revealed a link between formal ADHD diagnosis and higher mind-wandering trait (Mowlem et al., 2016; Biederman et al., 2017, 2019; Mowlem et al., 2019), in particular among adults who have higher level of inattention and hyperactive symptoms (Biederman et al., 2017, 2019). In this clinical context, higher mind-wandering propensity was also associated with lower executive functioning, emotional and psychopathological disturbances as well as a decrease in the quality of life (Biederman et al., 2019). Finally, with respect to the intentional or unintentional mind-wandering nature, spontaneous mind-wandering propensity was associated with higher levels of ADHD symptoms in both clinical and non-clinical samples (Arabacı and Parris, 2018; Biederman et al., 2017; Mowlem et al., 2019; Seli et al., 2015a).

Like mind-wandering, daytime sleepiness is common phenomenon described in ADHD. Cohort and cross-sectional studies have systematically reported that adults with formal diagnosis of ADHD experience increased subjective daytime sleepiness (EDS) rated on the Epworth Sleepiness Scale (ESS) (Oosterloo et al., 2006; Yoon et al., 2013; Sobanski et al., 2016; Bioulac et al., 2015; Lopez et al., 2018). A study performed by our group reported that 47% of ADHD patients rated above the ESS clinical cut-off score of 10/24; 22% of patients fulfilled the DSM-5 criteria for hypersomnolence disorder, characterized by EDS, long and undisturbed nighttime sleep (Lopez et al., 2018). Finally, a very recent systematic review performed on five studies examining a total of 328 patients reported that the prevalence of ADHD symptoms was > 30% in narcolepsy (Kim et al., 2020). The nature of the link between sleepiness and ADHD remains an open question that may involve either cause–effect relationship or intrinsic features of a similar neurodevelopmental dysfunction.

In general population and in various clinical samples, EDS is strikingly associated with similar deleterious consequences as mind-wandering across both attentional and executive cognitive domains. In fact, in college students, increased subjective EDS results in slower reaction times, lower accuracy during attentional tasks (Killgore, 2010; Short and Banks, 2014), and lower academic performances (Hershner and Chervin, 2014). We documented that objective EDS as assessed by multiple sleep latency tests was associated with poorer executive performances in patients with narcolepsy; while subjective EDS was related to higher attentional complaint (Bayard et al., 2012). Finally, EDS is recognized as a predictive sign of traffic accidents and driving impairment in both non-clinical samples (Philip et al., 2013; Garbarino et al., 2001; Ozer et al., 2014) and in sleep-disordered breathing (Zhou et al., 2016). In adults with a formal ADHD diagnosis, EDS was associated with a poor attentional control with negative impacts on driving performance and executive functioning (Bioulac et al., 2015; Cohen et al., 2019; Curry et al., 2017; Owens et al., 2013).

To sum up, attentional processing and executive control are involved in the emergence of mind-wandering. Sleepiness is accompanied by reduced attentional performances and executive control. Mind-wandering and sleepiness are two phenomena independently related to ADHD symptoms or diagnosis. In this clinical context, both are associated with deleterious consequences on attentional and executive functioning which are characteristic features of ADHD cognitive profile. To our knowledge, no studies have been conducted in adults with a formal diagnosis of ADHD to explore mind-wandering using experience sampling. Given that background and on the basis of these previously established associations, we hypothesized that patients with formal diagnosis of ADHD would show increased mind-wandering propensity, especially unintentional mind-wandering. In this respect, this propensity should be associated with increased EDS and detrimental effect on sustained attentional performances. In the present study, we used the online experience sampling of mind-wandering episodes and subjective sleepiness during a laboratory task, and also assessed self-reported mind-wandering propensity and sleepiness in daily life.

2. Material and methods

2.1. Participants

Twenty-five adults with ADHD were recruited from the Adult ADHD outpatient clinic of the Gui de Chauliac Hospital, Montpellier, France. All patients were diagnosed according to the DSM-5 criteria using a standardized face-to-face clinical interview (American Psychiatric Association, 2013; DIVA. 2.0). Newly diagnosed patients (n = 14) were met only few days after being diagnosed and thus before the initiation of any stimulant treatment. Eleven patients were enrolled during their psychiatric routine clinic visit with their attending psychiatrist (R.L.), and were asked to stop their stimulant treatment (methylphenidate) for at least 24 h prior to evaluation.

The control group consisted of 28 participants from the general population with no history of neurological or psychiatric disorders. They were community-dwelling adults who were recruited by means of advertisements and personal contacts and through snowballing techniques. They were met at the Laboratory Epsylon (University Paul Valery Montpellier 3). All participants spoke French fluently.

The study was conducted in accordance with the Declaration of Helsinki (World Medical Association, 2013) and was approved by the competent ethics committee. After a complete description of the study, written informed consent was obtained. Participants received no financial compensation.

2.2. SART with embedded thought-probes and KSS

Sustained Attention to Response Task (SART) in which we embedded thought-probes (Stawarczyk et al., 2011; Stawarczyk and D'Argembeau, 2016) and the Karolinska Sleepiness Scale (KSS; Akerstedt and Gillberg, 1990) were used. In this adaptation of the SART, numbers from 1 to 9 were presented successively in the center of a computer screen for 500 ms with an interstimulus interval of 2000 ms. Five hundred and forty numbers were presented in total. The instruction was to respond as fast and accurately as possible to each number (nontarget stimuli) by pressing the right button of a mouse, except for the number 3 (target stimulus, 11% of probability of occurrence). The task comprised 30 blocks of 35, 45, 55 or 65 s presented in a pseudorandom order.

After each block, participants were invited to complete the KSS. The KSS is a measure of subjective sleepiness that consists in a 9-point Likert scale ranging from 1 = *completely alert* to 9 = *very sleepy, great effort to keep awake*. Right after, participants were asked to specify the ongoing mental state they had just prior the interruption (Stawarczyk et al., 2016). Five choices were provided: (1) on-task: the participant was fully focused on the task; (2) task-related interference: the thoughts of the participant were related to the task features or about his/her performance; (3) distraction: the participant was temporally disengaged from the task by an internal (e.g., interoceptive sensations) or external distractor; (4) mind-wandering: the participant has disengaged attention from the task and had self-generate thoughts; (5) mind-blanking: this mental state is characterized by the absence of reportable content, the mind seems empty.

During the SART, when participants reported a mind-wandering episode, they were asked to write a short description about its content. The participants were informed that their descriptions should be detailed enough to be clearly recalled after the task. The purpose of this procedure was to facilitate the future content recall of each mind-wandering episode possibly reported by the participants during the probes. Indeed, at the end of the SART, participants were asked to characterize the phenomenally of their mind-wandering episode(s) on the Thought Characteristics Questionnaire (TCQ). No mention was made about the TCQ (see below) at this point of the task.

The primary outcome measure of the SART was the total error score (commissions + omissions). Two measures of reaction time (RT) were assessed. The first one was the mean RTs in ms, calculated over correct response trials, i.e. key presses after anything but a “3". The second was the RT variability in ms, quantified as the coefficient of variation of RT for correct responses trials. This is the standard deviation divided by the mean RT (RTcov).

2.3. Self-report questionnaires

The Adult ADHD Self Report Scale v1.1 (ASRS) (Kessler et al., 2005; Morin et al., 2016) is an 18-item self-report scale that contains all based DSM-IV inattentive and hyperactive-impulsive symptom criteria reworded to be more appropriate for adolescents and adults. Each symptom is rated on a 4-point Likert scale, and total scores range from 0 to 72. The general ADHD factor was computed as well as the Inattention, Hyperactivity and Impulsivity factors (Morin et al., 2016).

The Epworth Sleepiness Scale (*ESS*) (Johns, 1991) describes eight different situations, in which the participant is asked to rate the likelihood of falling asleep. For each situation the score ranges from 0 to 3, with a maximum sum score of 24.

The Daydreaming Frequency Scale (*DDFS*) (original scale by Antrobus et al., 1970, French version by Stawarczyk et al., 2012) is a retrospective measure of mind-wandering and daydreams. It consists of 12 items. Respondents are asked to rate the extent to which they experience daydreaming in their daily life with reference to a 5-point Likert-scale. Total scores can range from 12 to 60.

The Thought Characteristics Questionnaire (TCQ, Stawarczyk et al., 2016). The TCQ is a self-reported tool dedicated to assess the phenomenological dimensions of mind-wandering episode during the SART. For each episode produced, one TCQ was proposed. The following dimensions were assessed with 7-point Likert scales (1 = *not at all*, 7 = *totally*): (1) the thought involved visual imagery, (2) the thought involved inner speech, (3) the occurrence of the thought was intended and intentional, (4) the thought belonged to a structured succession of thoughts, (5) the content of the thought was realistic/plausible, (6) the content was of importance to the participant's life, (7) the thought often comes to the participant's mind in daily life (1 = *never*, 7 = *very often*). The affective valence of the thought (−3 = *very negative*, 3 = *very positive*), its temporal orientation (i.e. past, present, future, or no precise temporal orientation), and functions (i.e. to make a decision/solve a problem, to plan something, to reappraise a situation, to help to stay awake/alert, another unlisted functions, no apparent function) were also evaluated.

Study procedure The research protocol was carried out by a trained final year master's student in psychology at the University Paul Valery Montpellier 3 (Montpellier, France) (C.M.) from October 2018 to March 2019. All participants were individually tested during a single session in a quiet and well-lighted room.

Participants first completed an informed consent and completed some demographic and anamnestic questions. They then responded to some questionnaires (ASRS, ESS, and DDFS) before completing the SART with embedded thought-probes and KSS. Right after the SART, participants filled in the TCQ for each mind-wandering episode produced during the task. At this point in the procedure, participants could access the descriptions they had made about each episode of mind-wandering that may have occurred during the probes. In total, the testing session lasted around 60 to 75 min.

2.4. Statistical analyses

All statistical analyses were performed with IBM SPSS software version 24.0. Data were tested for homogeneity of variance using the Levene test. No normal distribution was considered when absolute values for skewness and kurtosis were greater than 3 and 10, respectively (Weston and Gore Jr., 2006). For normally distributed data, parametric tests were used (Student's *t*-test, analysis of variance, and Greenhouse-Geisser adjusted degrees of freedom). To examine whether sleepiness rated on KSS increased with time on task, we used a repeated analysis of variance with Group (2) as between-subject factor and Block (2) as the within-subject factor.

Same statistical designs were applied to examine the relationships and the interactions between Group (2) and Categories of thought-probes responses (5) with number of responses depending on categories of thought-probes, degree of sleepiness and SART performances as dependent variables. In the case of a significant effect of the variable Categories of thought-probes responses, contrast analyses focused on comparisons between on-task responses category and the four other categories of mental states (i.e., task-related, distraction, mind-wandering and mind-blanking responses).

Significantly abnormal distributions were tested with nonparametric methods (Mann-Whitney U test and Chi-square test). In addition, we calculated the eta squared η^2 and the Cohen's d' as measures of the effect size. The effect size was considered small ($\eta^2 = 0.01$; $d = 0.2$), medium ($\eta^2 = 0.06$; $d = 0.5$), or large ($\eta^2 = 0.14$; $d = 0.8$) according to (J. Cohen, 1988). To test for potential relationships between variables in the whole sample and in groups, we calculated Pearson correlations (with *rs* of 0.10, 0.30, and 0.50 defined as small, medium, and large effect size, respectively (Cohen, 1988). All analyses were conducted with a significance threshold of $\alpha \leq 0.05$, two-tailed.

3. Results

3.1. Demographic and clinical characteristics

Among the 25 ADHD patients included in the present study, 13 (52%) had a combined presentation and 12 (48%) with the predominantly inattentive presentation. One patient had current comorbid mood disorder and five (20%) also had current substance use disorder. As documented in Table 1, no significant difference was observed regarding age ($p = 0.16$), gender ($p = 0.95$) and education ($p = 0.55$). With regard to education, 52% of patients had at least a high school education; 36% had a university degree. These proportions were not significantly different from those observed among controls (respectively, 61% and 50%; $\chi^2 = 5.9$, $p = 0.43$). As expected, patients experienced higher level of ADHD symptoms on the ASRS than did controls (all *ps* < 0.05). Untreated patients had significantly higher levels of hyperactivity symptoms than treated patients ($p = 0.03$). No group differences were found for demographics data and all other clinical variables assessed. These results are presented in online supplementary

Table 1
Demographic, clinical characteristics and questionnaires for ADHD patients and controls.

Variables	ADHD Patients $n = 25$	Controls $n = 28$	t/χ^2	p
Demographic characteristics				
Age (years)	33.4 ± 11.3	28.9	−1.4	0.16
Gender (female)	60%	60.7%	0.003	0.95
Educational level (years)	14.1 ± 2.7	14.2 ± 1.8	−0.59	0.55
Clinical characteristics				
ADHD type				
Inattentive	52%	_	_	_
Mixed	48%	_	_	_
Mood disorders (present)	4%	_	_	_
Addiction disorders (present)	20%			
Questionnaires				
ADHD Self-report Scale				
Total	46.6 ± 9.4	29 ± 9.1	−6.9	**<0.001**
Inattention	27.5 ± 4.7	15.5 ± 4.5	−9.4	**<0.001**
Hyperactivity	9.8 ± 3.7	6.8 ± 3.7	−2.9	**0.005**
Impulsivity	8 ± 4.1	6 ± 2.7	−2.1	**0.04**
Epworth Sleepiness Scale	9.5 ± 5.3	8.3 ± 3.9	−0.8	0.38
Daydreaming Frequency Scale	49.8 ± 8.6	37.3 ± 8.6	−4.8	**<0.001**

ADHD, attention-deficit/hyperactivity disorder.
$p < 0.05$.

materials.

3.2. Mind wandering

3.2.1. Self-reported questionnaires

As documented in Table 1, higher trait of mind-wandering rated on the DDFS was observed in ADHD patients compared to controls ($p <$ 0.001, $d' = 1.45$). On the whole sample, self-reported mind-wandering propensity rated on the DDFS was positively and strongly correlated with the total ASRS score ($r = 0.68$). Same pattern of results was observed for the Inattention ($r = 0.62$), Hyperactivity ($r = 0.59$) and Impulsivity ($r = 0.34$) factors with moderate to large effects.

3.2.2. Sustained attention to response task with embedded thought-probes

Number of responses for the five categories of thought-probes was computed for ADHD group and control group. A 2 (Group) × 5 (Category) ANOVA with number of responses for each category of thought probes as dependent variable was performed. These results are illustrated in Fig. 1. No significant group-difference was noticed concerning this variable ($F = 1.12$, $p = 0.29$). However, we observed an effect of the thought-probes categories ($F = 41.47$, $p < 0.001$, $\eta^2 = 0.45$). Contrast analyses revealed that participants produced more frequently on-task responses than task-related interferences, distraction, mind-wandering, mind-blanking (all $ps < 0.001$) responses. The group x category interaction was significant ($F = 7.51$, $p = 0.002$, $\eta^2 = 0.13$). During the SART, ADHD patients produced significantly lower on-task responses than did controls ($p = 0.006$). They also reported more frequently mind-wandering ($p = 0.005$) and mind-blanking ($p = 0.02$) responses. No group-difference was observed with regard to task-related inferences ($p = 0.47$) and distractions ($p = 0.16$) responses.

Note that, this analysis was carried out by introducing sleepiness as a covariate (i.e. average KSS total score). As observed in the initial statistical model, no group effect was observed ($F = 1.53$, $p = 0.22$). The effect of the thought-probes categories remained significant ($F = 30.78$, $p < 0.001$, $\eta^2 = 0.38$) with same pattern of results for contrast analyses (all $ps < 0.001$). However, the group x category interaction did not reach significance ($F = 2.35$, $p = 0.19$). This analysis clearly indicates that the difference in the level of sleepiness between the groups induces greater mind-wandering propensity in patients than in controls.

Note that, on-task responses were negatively and strongly associated with task-related, distraction, mind-wandering and mind-blanking responses (respectively, $r = -0.69$; $r = -0.68$; $r = -0.63$; $r = -0.55$). Mind-wandering and mind-blanking rates were positively related ($r = 0.44$). Higher trait of mind-wandering rated on the DDFS was positively associated with the number of mind-wandering responses on the SART ($r = 0.36$). The ASRS total score and Inattention dimension were both moderately and negatively related to the on-task responses (respectively, $r = -0.35$ and $r = -0.39$). Mind-wandering responses on the SART was moderately to strongly positively correlated to the ASRS (Total, $r = 0.51$; Inattention, $r = 0.52$; Hyperactivity, $r = 0.28$; Impulsivity, $r = 0.35$). Mind-blanking was moderately linked to the ASRS total score ($r = 0.35$) and Inattention dimension ($r = 0.39$).

As documented in Table 2, group-differences were observed with respect to the phenomenological properties assessed by the TCQ of the reported mind-wandering episodes. In fact, mind-wandering episodes produced by ADHD patients were less intentional ($p = 0.01$, $d' = 0.41$), less structured ($p = 0.01$, $d' = 0.24$) and belonged less frequently to a structured succession of thoughts ($p = 0.04$, $d' = 0.28$). In both groups, mind-wandering responses were mainly future-oriented with no group differences ($p = 0.53$). Concerning their attributed functions, mind-wandering had mostly decision making/problem solving, planning something or reappraising a situation functions without between group difference ($p = 0.55$).

3.3. Sleepiness

3.3.1. Self-reported questionnaires

No group difference was observed for the ESS ($p = 0.38$) (Table 1). However, on the whole sample, self-reported sleepiness rated on the ESS was positively and weakly correlated with the ASRS score ($r = 0.21$). Same pattern of associations was observed for Inattention ($r = 0.28$) and Impulsivity ($r = 0.12$) factors whereas this association was inexistent for Hyperactivity factor ($r = 0.006$).

3.3.2. Sustained attention to response task with embedded thought-probes

Composite KSS average scores of the first (1–15) and second half (16–30) of though-probes were computed. As illustrated in Fig. 2, a 2 (Group) × 2 (Block) multivariate repeated-measures ANOVA showed a significant group effect ($F = 9.83$, $p = 0.003$, $\eta^2 = 0.16$) with ADHD patients experiencing higher level of sleepiness than did controls (Fig. 2). A significant block effect (1–15 versus 16–30) was also observed with increased level of sleepiness during the second half thought-probes compared to the first half ($F = 26.09$, $p < 0.001$, $\eta^2 = 0.34$). The group x block interaction did not reach significance ($F = 2.72$, $p = 0.11$). Note that the average KSS total score was very weakly associated with the ESS ($r = 0.14$) and moderately related to the ASRS total score ($r = 0.39$) and Attention dimension ($r = 0.47$).

3.4. Sustained attention to response task performances

A 2 (Group) × 5 (Category) ANOVA on SART performances revealed a significant Category effect for the error ($F = 4.4$, $p = 0.001$) and RTcov ($F = 3.6$, $p = 0.002$) variables. Concerning the error score, contrast analyses indicated that participants were less accurate when they produced on-task responses compared to mind-wandering responses, respectively, 17.14 ± 11.67 vs. 6.21 ± 5.19, $p = 0.003$. With regard to RTcov variable, participants had less variability in performance for mind-wandering responses compared to on-task, respectively, 0.92 ± 0.88 vs. 2.33 ± 1.57, $p = 0.01$.

These counterintuitive results can be explained by the fact that, on

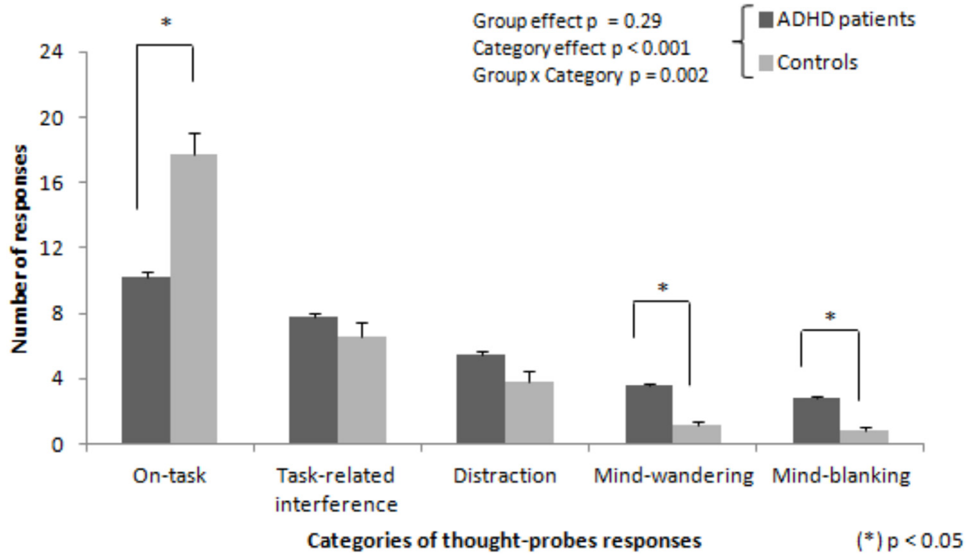

Fig. 1. Number of responses depending on categories of thought-probes responses for ADHD patients and controls. Error bars represent the *SEMs*.

Table 2
Phenomenological dimensions of mind-wandering for ADHD patients and controls rated on the Thought Characteristics Questionnaire.

Variables	ADHD Patients $n = 25$	Controls $n = 28$	t / χ^2	p
Visual imagery	4.2 ± 2.4	4.1 ± 2.2	−0.2	0.83
Inner Speech	5.3 ± 1.8	4.9 ± 2.4	−0.8	0.40
Intended/Intentional	1.8 ± 1.2	2.7 ± 1.6	−2.5	**0.01**
Structured	2.9 ± 1.9	4.0 ± 1.9	−2.6	**0.01**
Realism	6.0 ± 1.5	5.7 ± 1.8	−0.80	0.42
Project	3.4 ± 2.4	2.9 ± 2.5	−1.0	0.31
Importance	3.8 ± 2.4	4.4 ± 2.4	1.1	0.27
Repetitiveness	2.5 ± 1.8	3.4 ± 2.4	2.0	**0.04**
Affective valence	0.4 ± 1.5	0.4 ± 1.8	−0.06	0.95
Temporal orientation,%				
Future-oriented	49	46	2.1	0.53
Toward the present	20	21		
Toward the past	20	14		
No precise orientation	11	21		
Function,%				
To make a decision/solve a problem	18	24	3.0	0.55
To plan something	17	21		
To reappraise a situation	11	14		
To help stay awake/alert	5	0		
Another unlisted function	19	21		
No apparent function	31	21		

ADHD, Attention-deficit/hyperactivity disorder.
All mean range from 1 to 7 except for the affective valence dimension the range of which goes from −3 to 3.

one hand, RTcov globally decreased over though probes and that, on the other hand, mind-wandering and on-task responses had a different distribution over the course of the task. In fact, on the whole sample, lower rate of mind-wandering was observed during the first-half of though probes compared to the second-half (51 versus 70) with no group difference. Inverse pattern was observed for on-task responses ($\chi^2 = 17.42, p < 0.001$). RTcov of the first-half of though probes were higher than those of the second-half (3.72 ± 1.16 versus 0.36 ± 0.19; $t = 3.04, p < 0.001$).

We found no group effect for RT ($F = 0.91, p = 0.35$) and RTcov ($F = 1.6, p = 0.22$) indices. A statistical tendency was observed for the error score ($F = 3.7, p = 0.07$). Patients were less accurate than controls, respectively, 48.3 ± 31.1 vs 77.8 ± 43.9. Interactions were not significant, respectively, $F = 1.8$, $p = 0.15$; $F = 0.28$, $p = 0.81$; $F = 1.6, p = 0.22$.

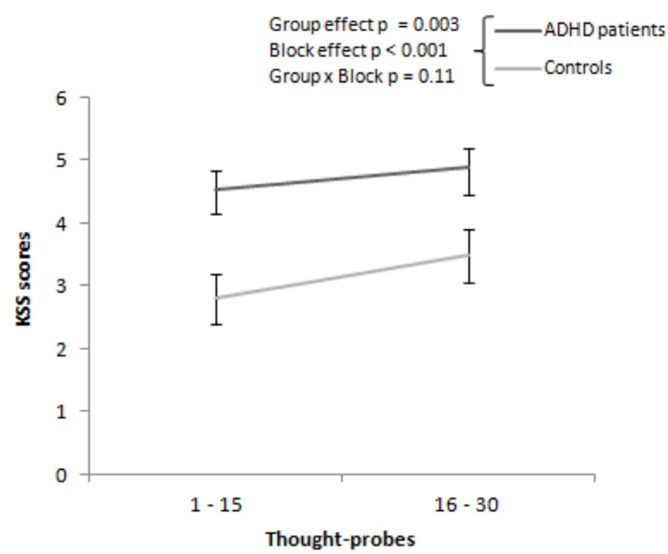

Fig. 2. KSS scores of the first and second half of though-probes for ADHD patients and controls. Error bars represent the *SEMs*.

All correlations computed between SART primary measures (i.e. error score, RT and RTcov) and the average KSS total score were not statistically significant (all *rs* < 0.20). Same pattern of results was noted with regard to the ASRS score.

3.5. Relationship between degree of sleepiness and mind-wandering

Average KSS scores were computed for each category of thought-probes responses across the 30 probes (Fig. 3). A 2 (Group) × 5 (Category) ANOVA with KSS scores as dependent variable was performed. A significant group effect ($F = 4.31, p = 0.05, \eta^2 = 0.22$) was noted with ADHD patients experiencing higher level of sleepiness than did controls. A category ($F = 3.64, p = 0.05, \eta^2 = 0.32$) effect was also noted. Contrast analyses revealed that mind-wandering and mind-blanking were associated with higher levels of sleepiness compared to being fully focused on task, respectively, $p = 0.049, p = 0.03$ (Fig. 3). No significant differences were observed between task-related, distraction and on-task responses, respectively, $p = 0.24, p = 0.08$. The group × category interaction was not significant ($F = 0.45, p = 0.59$). In accordance with these results, self-reported mind-wandering

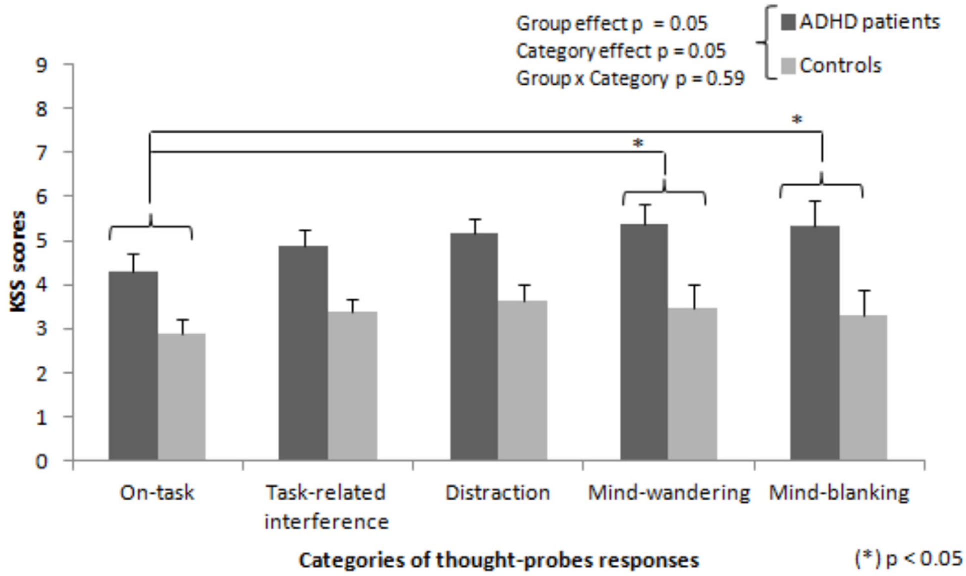

Fig. 3. KSS scores depending on categories of thought-probes responses for ADHD patients and controls. Error bars represent the *SEMs*.

propensity rated on the DDFS were moderately and positively correlated with the average KSS score ($r = 0.41$). No association was found between the ESS and DDFS scores ($r = 0.05$).

The average KSS total score was negatively and strongly associated with the on-task responses ($r = -0.55$). Inverse and moderate associations were found for the other four mental states (task-related, $r = 0.28$; distraction, $r = 0.34$; mind-wandering, $r = 0.38$; mind-blanking, $r = 0.46$).

4. Discussion

This study demonstrates for the first time that patients with formal diagnosis of ADHD show increased mind-wandering propensity using experience sampling. In both groups, mind-wandering episodes were mostly future-oriented. Nevertheless, in patients with ADHD, they were less intentional and less structured, and belonged less frequently to a structured succession of thoughts. We also observed that patients with ADHD reported higher rate of mind-blanking compared to control participants. In both groups, mind-wandering and mind-blanking responses were significantly associated with higher level of sleepiness compared to on-task responses. These two mental states were also linked to higher level of inattentive symptoms. Self-reported mind-wandering propensity was related to both subjective sleepiness and ADHD symptoms severity. Finally, even if patients performed worse than did controls on the SART, neither sleepiness nor mind-wandering were related to SART performances.

Through the application of an experience sampling paradigm, our results corroborate those of previous studies that have described the association between ADHD diagnosis and mind-wandering propensity rated on self-reported measures, i.e. Mind-Wandering Questionnaire (Biederman et al., 2019, 2017) and Mind Excessively Wandering Scale (Mowlem et al., 2016). In accordance with these two studies and past works performed on non-clinical samples (Seli et al., 2015; Franklin et al., 2017; Jonkman et al., 2017; Arabacı and Parris, 2018), we also reported a positive association between self-reported mind-wandering propensity and the severity of inattentive, hyperactive/impulsive symptoms. More specifically, the factorial organization of the ASRS including one general ADHD factor and three specific factors (Morin et al., 2016) allowed us, for the first time, to document that hyperactive and impulsive symptoms were each related to self-reported mind-wandering propensity. Overall, these results several times replicated by means of various paradigms (i.e. self-reported measures vs thought-probe methods; groups of patients with formal ADHD diagnosis vs non-clinical samples) define mind-wandering as a prototypical feature of ADHD.

In the present study, we were also interested in characterizing the phenomenological dimensions of mind-wandering thought contents. On the whole sample, our results were consistent with previous researches indicating that mind-wandering is commonly characterized by a prospective bias (i.e. planning, solving a problem, decision making, reappraisal of situations) (Smallwood et al., 2009; Stawarczyk et al., 2011; Stawarczyk and D'Argembeau, 2016; Stawarczyk, 2017). It is now well admitted that mind-wandering can occur deliberately, with intention, or spontaneously, without intention, (Seli et al., 2017; Carriere et al., 2013; Seli et al., 2015; Giambra, 1989). In lines with previous observations made on non-clinical samples, we found that spontaneous, but not deliberate, mind-wandering reported during probes was related to ADHD diagnosis (Shaw and Giambra, 1993; Seli et al., 2015; Arabacı and Parris, 2018). Spontaneous, unintentional shifting of attention is a core diagnostic criterion of ADHD, i.e. “Often does not seem to listen when spoken to directly (e.g., mind seems elsewhere, even in the absence of any obvious distraction)” (American Psychiatric Association, 2013). This specific symptom reflects difficulties in controlled processing, problems with inhibiting distracting information, and unintentional task inattention (Carriere et al., 2013; Seli et al., 2015). The fact that in our study mind-wandering episodes were less structured and belong less frequently to a structured succession of thoughts reinforces this idea. For their part, deliberate, intentional shifts reflect more the willing engagement of thought, which is more indicative of controlled processing (Carriere et al., 2013; Seli et al., 2015). Thus, considering these subtypes of mind-wandering in the context of ADHD, a more nuanced hypothesis is that spontaneous, but not deliberate mind-wandering, is associated with ADHD diagnosis.

Higher level of subjective sleepiness rated on the ESS is systemically reported in ADHD patients (Sobanski et al., 2016; Bioulac et al., 2015; Lopez et al., 2018; Oosterloo et al., 2006; Yoon et al., 2013). Our results contrast with these observations. In fact, we found no significant difference between patients and controls on the ESS. A possible explanation may lie in the fact that the average ESS score of our control group was particularly high (8.3 ± 3.9). In fact, this average value is definitely higher than those described in various studies on normative data for ESS: 4.6 ± 2.8 (M. Johns and Hocking, 1997), 4.5 ± 3.3 (Parkes et al., 1998), 5.9 ± 3.8 (Ferreira et al., 2006), 7.5 ± 3.9

(Geisler et al., 2006). Despite this negative result, ADHD patients still reported higher level of sleepiness on the KSS than did controls. This difference can be explained by the fact that these two scales do not evaluate exactly the same characteristics of sleepiness. In fact, the ESS measures sleep propensity in different situations of daily living (Johns, 1991); the KSS is dedicated to assess discrete changes in sleepiness over time. The KSS is particularly sensitive to the attentional load required by the context in which the sleepiness rating is performed (Akerstedt et al., 2008). This observation is in accordance with our results showing an increase in sleepiness as the task progresses in both groups.

In our work, we were particularly interested in exploring relationship between sleepiness and mind-wandering phenomena in ADHD. We found that mind-wandering and sleepiness were frequently co-occurring in ADHD suggesting that these two phenomena might also be partially underlined by common mechanisms in this clinical context. To the best of our knowledge, two studies have directly investigated this relationship in non-clinical samples showing that these two phenomena were associated. The first one exactly applied the same protocol that we used in the present study (Stawarczyk and D'Argembeau, 2016) and the second one relied on self-reported questionnaires including the ESS (Carciofo et al., 2014). In an indirect way, our results are also in line with studies that have documented an association between poor sleep quality in ADHD, sleep deprivation in healthy controls and mind-wandering propensity (Helfer et al., 2019; Poh et al., 2016). As poor sleep quality and sleep deprivation are major causes of sleepiness in both clinical and non-clinical samples (Ohayon, 2012), we can hypothesize that sleepiness could mediate the relationship between poor sleep and mind-wandering. Mind-wandering and sleepiness are similar in terms of the EEG signal (i.e. increase of theta and delta EEG activity; decrease of alpha and beta activity) and both are linked to the default mode network (DMN) activity (Braboszcz and Delorme, 2011; Christoff et al., 2016). The DMN is now recognized as the main neural basis linked to mind-wandering activities (Callard et al., 2013) and is also involved in alertness and sleep physiology (Sämann et al., 2011; Horovitz et al., 2009). In non-clinical sample, sleepiness exhibited significant coactivation of parts of DMN and executive control network (Stoffers et al., 2015; Ward et al., 2013). In ADHD, it has been suggested that the DMN is inadequately attenuated, leading to interference with cognitive processes (e.g. attention and executive control) required for goal-directed task performance, that are reflected in ADHD symptoms (Sonuga-Barke and Castellanos, 2007; Bozhilova et al., 2018). In that context, a possible explanation for the frequent co-occurrence of mind-wandering and sleepiness might stem from a decrease brain arousal leading to decrease in attentional and executive abilities. Unfortunately, we failed to document relationships between mind-wandering, sleepiness and SART performances in our sample. However, the fact that patients described their mind-wandering episodes as less intentional than did controls, and the strong association reported between level of inattention symptoms and mind-wandering on the whole sample support indirectly this idea.

Even if mind-blanking remains a phenomenon poorly understood, authors broadly agree that it is distinguishable from mind-wandering in terms of phenomenology (Schooler et al., 2004; Ward and Wegner, 2013). Mind-blanking is generally defined by a lack of conscious awareness in the course of which the individual is not focally aware of any stimuli, either internal or external. In that sense, this mental state would represent an extreme decoupling of perception and attention. A part of our results is in line with those of Van den Driessche et al. (2017) who documented that college students with subclinical ADHD had higher mind-blanking episodes during a SART protocol with embedded thought-probes quite similar of ours (Van den Driessche et al., 2017). In this study, mind-blanking propensity was at the expense of mind-wandering and on-task responses. No association was found between mind-wandering and subclinical ADHD. These last results are difficult to integrate into our observations. In fact, we found a positive association between mind-wandering and mind-blanking ($r = 0.44$), and ADHD diagnosis was related to higher mind-wandering as widely documented in the literature (Lanier et al., 2019). In the same way as for mind-wandering, we reported that mind-blanking was linked to higher level of sleepiness and inattentive symptoms. These results are in lines with the neuroscience literature showing an association between mind-blanking, reduction in pupil diameter and increase in subjective sleepiness (Unsworth and Robison, 2018). This mental state has been also related to a positive activation of medial prefrontal cortex which is involved in the DMN (Kawagoe et al., 2019). In that context, one can hypothesize that mind-blanking episodes could reflect confused states in the stream of consciousness that are associated with a decrease of wakefulness where the mind wanders anywhere (Poudel et al., 2018). One argument in favor of this hypothesis is the reverse effect of methylphenidate on the level of mind-blanking in children with ADHD (Van den Driessche et al., 2017). Most psychostimulants (modafinil, methylphenidate, and amphetamines) increase wakefulness, possibly by inhibiting the dopamine transporter function and increasing cortical and caudate dopamine concentrations (Wisor and Eriksson, 2005).

Several limitations should be taken into consideration when interpreting our results. First, the sample size is low although sufficient to demonstrate significant higher mind-wandering experience during a probe-caught task in ADHD patients. Therefore, our findings need to be viewed as preliminary until replicated in larger samples. Second, all patients were not drug-naïve; some were weaned from their stimulant treatment for the study. However, overall, the two groups did not differ significantly in terms of their demographic and clinical characteristics. Third, controls did not undergo an assessment of ADHD, which may have resulted in overlooking ADHD. Nevertheless, none of controls reported ever being ADHD diagnosed in their entire lifetime. Fourthly, we did not conduct a measure of intelligence. A recently published meta-analysis involving over 600,000 participants from the general population have documented that individuals with a propensity toward higher intelligence tend to complete more years of education (Ritchie and Tucker-Drob, 2018). More specifically, education has a causal effect on intelligence test scores. In our sample, no differences were observed between patients and controls in terms of educational attainment (including high school and university degrees). In order to comply with the thought probe procedure proposed by Stawarczyk and D'Argembeau (2016), we did not counterbalance the questionnaires and the SART. In this context, a carry-over effect can therefore not be totally rule out. Finally, we did not perform an objective evaluation of sleepiness by means of MSLT or MWT. However, even if there is no doubt about the association between subjective sleepiness and ADHD diagnosis (Sobanski et al., 2016; Bioulac et al., 2015; Lopez et al., 2018; Oosterloo et al., 2006; Yoon et al., 2013), this relationship remains matter of debate with regard to objective sleepiness (Sobanski et al., 2016; Bioulac et al., 2015).

5. Conclusion

The present study to our knowledge provides first initial/preliminary evidence for higher propensity of mind-wandering and mind-blanking using experience sampling in patients with formal ADHD diagnosis. This propensity was associated with sleepiness without negatively impacting sustained attention performances. Further studies interested in either of mind-wandering, mind-blanking and sleepiness in ADHD are needed to corroborate our results. The gap between the mind-wandering, mind-blanking and sleepiness areas needs also to be clarified in both ADHD and neurotypical individuals.

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Declaration of Competing Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.psychres.2020.112901.

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