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Mind wandering in children: Examining task-unrelated thoughts in computerized tasks and a classroom lesson, and the association with different executive functions

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ABSTRACT

Mind wandering is associated with worse performance on cognitively demanding tasks, but this concept is largely unexplored in typically developing children and little is known about the relation between mind wandering and specific executive functions (EFs). This study aimed, first, to measure and compare children's mind wandering in controlled computerized tasks as well as in an educational setting and, second, to examine the association between mind wandering and the three core EFs, namely inhibition, working memory, and set shifting/switching. A total of 52 children aged 9–11 years performed a classroom listening task and a computerized EF battery consisting of flanker, running span, and attention switching tasks. Mind wandering was measured using online probed and/or retrospective self-reports of task-unrelated thoughts (TUTs) during task performance. Children reported TUTs on 20–25% of the thought probes, which did not differ between classroom and EF tasks. Regression models, hierarchically adding the three core EFs, accounted for a small but significant portion of variance in TUT frequency when measured in class and retrospectively after EF tasks, but not when measured online in EF tasks. Children with worse inhibition were more prone to mind wander during classroom and EF tasks. Lower attention switching accuracy

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also explained variation in retrospectively reported TUTs during EF tasks. Working memory was not a significant predictor. These results suggest that mind wandering is common and reliably measurable in children in controlled computerized and educational tasks. Lower executive control abilities predict more frequent mind wandering, although different EFs are related to mind wandering in diverse tasks/measures.

Introduction

Mind wandering is a common everyday experience during which attention unintentionally shifts from the immediate external environment or task toward task-unrelated, self-generated thoughts (Smallwood & Schooler, 2015). This phenomenon occurs frequently, with 25–50% of our daily life thoughts being task unrelated (Kane et al., 2007; Killingsworth & Gilbert, 2010). Although the tendency to mind wander is in principle harmless or can even be beneficial, previous research has indicated a broad range of everyday situations in which mind wandering has detrimental consequences (e.g., Schooler, Reichle, & Halpern, 2004; Yanko & Spalek, 2013). In particular, in difficult and demanding tasks that require high levels of sustained attention or executive control, the tendency to mind wander is associated with worse task performance (Mooneyham & Schooler, 2013; Smallwood & Andrews-Hanna, 2013). Cognitively demanding tasks are very common in educational settings. Smallwood, Fishman, and Schooler (2007) indicated the relevance of mind wandering for education and hypothesized that mind wandering breaks down the integration of information from the external environment into internally represented schemas, which is central to learning. In adults, higher frequencies of mind wandering during reading texts, studying, and/or listening to lectures have indeed been related to worse performance on reading comprehension (Schooler et al., 2004), course examinations (Lindquist & McLean, 2011; Wammes, Seli, Cheyne, Boucher, & Smilek, 2016), and retention tests of (online) lecture material (Seli, Wammes, Risko, and Smilek, 2016; Szpunar, Moulton, & Schacter, 2013), respectively.

Despite its relevance for education, mind wandering is largely unexplored in children. To the best of our knowledge, as yet only two studies have measured mind wandering during cognitive task performance in typically developing children (Ye, Song, Zhang, & Wang, 2014; Zhang, Song, Ye, & Wang, 2015). Both studies showed that mind wandering can be validly measured from ages 8 to 10 years onward by using the so-called online thought probe method that is frequently used in adult mind wandering research. This method entails the periodical presentation of probes during performance of a task or in daily life, asking for self-report of whether one had on-task or off-task thoughts—also called task-unrelated thoughts (TUTs)—in the moments preceding presentation of the probe (Smallwood & Schooler, 2015). In both previous studies, children reported off-task thoughts in 35% of cases when task performance was interrupted by thought probes (Ye et al., 2014; Zhang et al., 2015), which lies within the frequency range of TUTs reported in adult samples (e.g., McVay & Kane, 2009; Smallwood & Schooler, 2015). Furthermore, the common finding that more TUTs are related to lower accuracy on the performed task was also replicated in children in a 1-back working memory task (Ye et al., 2014) and a sustained attention task (Zhang et al., 2015). However, a well-studied feature of mind wandering in adults, namely that the prospective bias of mind wandering (i.e., more future-oriented than past-oriented thoughts) decreases when task demands increase (Smallwood, Nind, & O'Connor, 2009), was not replicated in children (Ye et al., 2014). This suggests that the relation between mind wandering and cognitive abilities might be different in children compared with adults. This would be in line with the ongoing maturation of attentional and executive control skills, such as inhibition and working memory capacity, throughout childhood and adolescence (e.g., Huizinga, Dolan, & van der Molen, 2006; Keulers, Goulas, Jolles, & Stiers, 2012; Schleepen &

Jonkman, 2014). Given the importance of (meta)cognitive control for recognizing and correcting mind wandering in adults (e.g., Seli, Risko, Smilek, & Schacter, 2016; Smallwood, 2013; Smallwood et al., 2007), it would be relevant to study the association between executive control capacities and mind wandering frequency in children.

Cognitive or executive control is strongly related to two main characteristics of mind wandering: disengagement of the external task/environment, on the one hand, and generation of self-related thoughts, on the other (Smallwood & Schooler, 2015). Mind wandering can be beneficial or detrimental for task performance depending on the amount of executive capacity/mental resources needed for adequate task performance (Smallwood & Schooler, 2015). In easy tasks that demand only low levels of executive/attentional control, engaging in self-generated thought might be beneficial for performance (Baird, Smallwood, & Schooler, 2011; Levinson, Smallwood, & Davidson, 2012; Robison, Gath, & Unsworth, 2017). A study by Smallwood, Ruby, and Singer (2013), for example, showed that when engaging in more self-generated thought in a task with low cognitive load, adults could endure longer delays to wait for a reward, which is evidence of better self-regulation. According to the executive control hypothesis (Smallwood & Schooler, 2006), this can be explained by more available resources for mind wandering when tasks are simple. However, in more cognitively demanding tasks, mind wandering has been shown to be detrimental for performance. According to the executive failure account of mind wandering (McVay & Kane, 2010), this is due to a failure of an individual's executive control system to inhibit automatically generated task-interfering thoughts. Individual differences studies in adults have found support for this theory by showing that working memory capacity (as a measure of an individual's executive/attentional control capacity) and mind wandering frequency are negatively related, especially when mind wandering is assessed in cognitively demanding tasks (Randall, Oswald, & Beier, 2014; Unsworth & Robison, 2016). In most of these studies, however, working memory capacity and mind wandering were assessed in different tasks, thereby not directly measuring the effects of the potential trade-off in executive resources needed for mind wandering and maintenance of task performance within one and the same cognitive task (Mrazek et al., 2012).

The vast majority of individual differences studies that have reported negative relations between cognitive control capacity and mind wandering in adults, however, focused on only one aspect of executive control, namely working memory capacity (but see Kane et al., 2016, for an exception), whereas executive control is an umbrella term for various cognitive processes that subserve goal-directed behavior. Using latent variable analyses, Miyake et al. (2000) distinguished three core executive functions (EFs)—namely set shifting/attention switching, working memory updating, and inhibition/interference control—which in adults have been shown to be separable but moderately correlated constructs. The only study to our knowledge that investigated relations between these three core EFs and mind wandering by measuring both within the same EF tasks is a study including healthy adults by Kam and Handy (2014). These authors found that mind wandering disrupted behavioral performance on inhibition and working memory tasks, but not on an attention switching task. In addition, the general tendency to mind wander in daily life, as measured by a self-report questionnaire, was negatively correlated with inhibition accuracy but was not related to performance on working memory and switching tasks (Kam & Handy, 2014). Although these results need replication, they at least suggest that specific executive dysfunctions might underlie mind wandering. How specific EFs relate to mind wandering in children, however, has not yet been examined.

Despite the spontaneous nature of mind wandering, its occurrence is mainly measured in controlled laboratory conditions. Although some adult studies have shown that mind wandering is a stable characteristic across controlled (laboratory) and ecological contexts (Kuehner, Welz, Reinhard, & Alpers, 2017; McVay, Kane, & Kwapil, 2009), others have indicated that the association between mind wandering and cognition differed between laboratory and daily-life settings (Kane et al., 2017). As discussed above, previous studies in children have used laboratory state measures (controlled computerized tasks) as well as trait measures (questionnaires) assessing children's tendency to mind wander during cognitive performance and in daily life (Ye et al., 2014; Zhang et al., 2015). However, to our knowledge, no studies have as yet assessed state mind wandering levels in children in an ecological setting such as in the classroom, which is important considering its potential effects on learning (Smallwood et al., 2007). To fill this gap, the first aim of the current study was to study and compare the frequency of state mind wandering (by using the online thought probe method) in typically developing children during the performance of controlled computerized (EF) tasks and in a classroom listening task (a regular lesson). The second aim of this study was to examine the associations between the three core EFs and children's state mind wandering reports during computerized tasks and a classroom lesson by administering an attention switching task, a working memory updating task, and an inhibition/interference control task. To compare our results with those of previous mind wandering studies in adults, we also included two questionnaires to measure children's self-reported trait mind wandering levels in daily life.

Method

Participants

Children were recruited from an international primary school in The Netherlands. All parents of children in Grade 5 were given an information letter explaining the study, including a passive informed consent request in which parents were asked to contact the researchers if they did not want their children to participate. After distributing the information letter, 2 weeks were given until measurements started. No parents objected to participation of their children. This resulted in three classes with a total number of 55 children taking part in the study. Because computerized (EF) task data could not be collected from 3 children, the final group consisted of 52 children (35 girls and 17 boys; age range 9–11 years, M = 10.12 years, SD = 0.42). The choice for this age range was among others based on results by Flavell, Green, and Flavell (2000), who showed that at least from 8 years of age children are aware of their own spontaneous ongoing ideation and are able to report on their thought content.

Procedure

First, children completed two questionnaires, the Attention Related Cognitive Errors Scale (ARCES) and Mindfulness Attention Awareness Scale adapted for Children (MAAS-C), in the classroom to measure their trait mind wandering levels in daily life. Subsequently, in the same classroom session, a novel listening task with online thought probes was administered to assess children's tendency to engage in TUTs in the classroom setting. The number of thought probes (6) was based on an earlier study in which mind wandering was measured during a lecture in college students (Lindquist & McLean, 2011). The task involved children listening to a text about road safety, read aloud in the classroom by their teacher, during which thought probes were presented. Children were given answer booklets to record their answers to the thought probes, with two answer categories for each probe question printed on a separate page (see "Behavioral tasks" subsection below). Before the task, children were given instructions and examples of on-task and off-task thoughts. The whole classroom session lasted approximately 30 min. In a second session, children performed a computerized EF battery comprising an attention switching task, a running span (working memory updating) task, and a flanker (response inhibition/interference control) task. During performance of these computerized tasks, thought probes were presented to measure TUTs during task performance (see "Behavioral tasks" subsection below). To record their answers to the thought probes, children were given an answer booklet. The computerized EF battery was administered in small groups of 5 children in a quiet testing room outside of the classroom. This second session lasted approximately 35 min. After completion of each of the three EF tasks, two questions were administered to assess retrospective reports of the experienced frequency of past and future TUTs during task performance.

The current study, including the above-mentioned informed consent procedure, was approved by the Ethical Review Committee Psychology and Neuroscience of Maastricht University (No. ECP-Master_162_7_2016).

Instruments

Questionnaires

The ARCES questionnaire (Carrière, Cheyne, & Smilek, 2008) measures the frequency of attention-related errors in daily life due to absentmindedness/mind wandering. The questionnaire comprises 12 items such as "I have gone to the fridge to get one thing (e.g., milk) and taken something else (e.g., juice)" and "I fail to see what I am looking for even though I am looking right at it." Children rated the occurrence of such errors based on the frequency with which they experience them on a 5-point scale ranging from 1 (*never*) to 5 (*very often*). The total score on the ARCES was used as a trait measure of mind wandering level in daily life.

The MAAS-C questionnaire (Lawlor, Schonert-Reichl, Gadermann, & Zumbo, 2014) assesses the level of mindlessness in everyday situations. It consists of 15 items such as "I could be feeling a certain way and not realize it until later" and "I snack without being aware that I'm eating." Questions were answered on a 6-point scale ranging from 1 (*almost never*) to 6 (*almost always*). The total score on the MAAS-C was used as a trait measure of mindlessness/absentmindedness level in daily life.

In addition, 2 items from the 8-item TUT subscale of the Dundee Stress State Questionnaire (DSSQ; Matthews, Szalma, Panganiban, Neubauer, & Warm, 2013) were used to assess TUT retrospectively during performance of the computerized EF tasks (directly after performance of each of the EF tasks). The 2 selected TUT items measured thoughts about the past ("While I was doing this task I thought about something that happened in the past") and future ("While I was doing this task I thought about something that I will do in the future"). Children answered these questions on a 5-point scale ranging from 1 (*never*) to 5 (*very often*). The total score on each of these questions across EF tasks was used as a retrospective state measure of mind wandering (EF-TUT retrospective) related to either past or future events.

Behavioral tasks

The classroom listening (CL) task was used to measure children's mind wandering frequency during a regular educational lesson. The text about road safety was read aloud to the whole classroom by the teacher and had an approximate duration of 15–20 min (the total text was 2818 words). At six equal intervals during the listening task, children were prompted by a thought probe asking them to choose one of the following two answer options written down in an answer booklet: "I was focused on what my teacher was talking about" (on-task thought; score 0) or "I was thinking about something else/not really focused on what my teacher was saying" (off-task thought/TUT; score 1). The total number of indicated TUTs was divided by 6 (total thought probes) and converted into a percentage by multiplying by 100. This percentage was used as an online index of TUTs during the classroom listening task (CL-TUT online).

The computerized EF battery consisted of an attention switching task, a running span (working memory updating) task, and a flanker (inhibition/interference control) task. Tasks were programmed using Presentation 18.1 (Neurobehavioral Systems, Berkeley, CA, USA). Before this study the currently used EF tasks were piloted in a sample of 63 children, and thereafter the tasks were administered (as part of a larger EF battery) in another (still ongoing) EF training study in children including a large ($N = 750$) sample of 9- to 11-year-olds (see Bervoets, Jonkman, Mulkens, de Vries, & Kok, 2018, for the protocol of this study). All three tasks were preceded by instruction screens and practice trials. Thought probes were inserted into each task at equal intervals (24 in total: 12 in the attention switching task, 6 in the running span task, and 6 in the flanker task) to assess children's mind wandering frequency during task performance. The thought probe screen presented the question "Just before this screen came up, what were you thinking about?" followed by two answer options: "the task" (on-task thought; score 0) or "something else" (off-task thought/TUT; score 1); children needed to choose between the answer options by selecting their favored one in an answer booklet. The total reported TUTs across the three EF tasks was divided by 24 (total thought probes) and converted into a percentage by multiplying by 100. This percentage score was used as an online index of children's TUT frequency during the EF battery (EF-TUT online).

The attention switching task measures the capacity to switch attention between different task instructions and is an adapted version of the one described by Cepeda et al. (Cepeda, Cepeda, & Kramer, 2000; Cepeda, Kramer, & Gonzalez de Sather, 2001). The task consisted of three separate blocks of trials: two nonswitch blocks (48 trials each) and one switch block (96 trials). Two response buttons were available to the children. In each trial, one of four stimuli could appear in the center of the screen with equal probability: the number 1, 3, 111, or 333. In the first nonswitch block, stimuli were preceded by a cue screen "WHICH NUMBER?" indicating that children needed to identify whether the presented stimulus contained the number 1 (press left button) or the number 3 (press right button) regardless of the number of presented digits. In the second nonswitch block, stimuli were preceded by a cue screen "HOW MANY NUMBERS?" indicating that children needed to identify how many digits the number was made up of by pressing the left button in case of a one-digit number or the right button in case of a three-digit number. During the final switch block, the cue screens alternated randomly between "WHICH NUMBER?" and "HOW MANY NUMBERS?" requiring children to switch between rules on approximately half of the trials. Each trial consisted of the presentation of a cue in the center of the screen, followed 200 ms later by one of the four stimuli, which remained on the screen until a response was given. Feedback was provided for the entirety of the task ("WRONG" in the event of an incorrect response and "FASTER" when a response was not provided within 3 s). This task included 12 thought probes spread evenly throughout trials. The difference in reaction time and percentage correct responses between switch trials and nonswitch trials (mean across the two nonswitch blocks) was calculated to obtain switch cost scores.

A number running span task was developed to measure working memory updating capacity in children. A letter version of this was used before by Miyake et al. (2000) in adults, and of the three included working memory tasks in Miyake et al.'s seminal study, the running span task correlated strongest with the working memory updating EF factor. In their developmental EF study, Lee, Bull, and Ho (2013) used a pictorial variant of the updating task; however, we opted for a number variant to avoid potential influences of semantic associations. Series of numbers (1–9) were presented one at a time in the center of the screen for 1 s, followed by an interstimulus interval of 500 ms. Children were instructed to remember the number sequence. After presentation of each number sequence, children were presented with a response screen showing the beginning *n* numbers of the sequence followed by question marks at the places where the missing numbers needed to be filled in (by using the keyboard on the laptop) based on what was still remembered in forward order of presentation (e.g., 3 7 2 ? ? ?). The last three numbers of a sequence always needed to be recalled. Four trials of five-, six-, and seven-number sequence lengths (12 trials in total) were presented randomly intermixed so that children could not predict the length of the upcoming sequence. This task included 6 thought probes presented every 2 trials. The mean percentage of correct responses across all trials was calculated (all numbers of a sequence needed to be recalled in the correct serial order to be counted as correct).

A letter version of the flanker task was used to measure children's response inhibition/interference control capabilities (Eriksen & Eriksen, 1974; see Jongen & Jonkman, 2008, for a developmental event-related potential (ERP) study using a Stroop variant of this task). The task consisted of six blocks of 24 trials. In each trial, children were presented with three letters appearing in the center of the screen. They were instructed to attend only to the letter in the middle, which could be a B, H, F, or T. Children were instructed to press the left button in case of a B or H or the right button in case of an F or T. The flanking stimuli were presented at both sides of the central target letter and were always identical to each other. There were three different stimulus categories occurring randomly and with equal probability within task blocks: (a) the *stimulus–response congruent* condition (where all three letters were the same and there was no stimulus or response conflict), (b) the *stimulus incongruent* condition (where the central target letter was different from the flanking letters but both letters were associated with the same response button, e.g., B and H), and (c) the *stimulus and response incongruent* condition (where the central target letter was different from the flanking letters and both letters were associated with a different button response, e.g., B and T, manipulating response conflict/inhibition). To prime attention to the flankers, trials began with the presentation of the two flanking letters for 200 ms, followed by the target letter, after which the three letters remained on the screen for a further 700 ms. This was followed by a 500-ms interstimulus interval during which a fixation cross appeared in the center of the screen. This task included 6 thought probes presented after each block of 24 trials. The difference in reaction time and percentage correct responses between stimulus and response incongruent (SRI) trials and congruent (C) trials was calculated to obtain inhibition/interference control efficiency scores.

Statistical analyses

There were missing data from 2 children on the running span task and from 1 child on the flanker task that were replaced by the mean scores of the remaining group of children (Tabachnick & Fidell, 2013). Data inspection indicated that the distributions of all mind wandering and EF variables were normal (skewness and kurtosis values between −1.5 and 1.5; Tabachnick & Fidell, 2013). Outliers were defined as scores of more than 3 standard deviations above or below the variable mean and were subsequently excluded from the relevant analysis. To investigate the degree to which different measures of mind wandering were associated, bivariate correlation analyses were performed. In addition, dependent *t* tests were used to examine differences in mind wandering frequency across task/measurement conditions. Hierarchical multiple linear regression analyses were conducted for the state mind wandering indexes (i.e., CL-TUT online, EF-TUT online, and EF-TUT retrospective). The accuracy scores on the three EF tasks were entered as predictor variables into the regression models. EF accuracy scores were chosen above reaction time measures because of their positive correlations with mind wandering measures, sufficient interindividual variation (mean accuracy <80%; Davidson, Amso, Anderson, & Diamond, 2006; Zelazo et al., 2013), comparability across tasks (i.e., the running span task has only accuracy as an outcome measure), and redundancy of the model. The purpose of these regression analyses was to explore whether specific EFs—attention switching, working memory, and inhibition—each accounted for a unique proportion of variance in children's mind wandering frequency. Inhibition/interference control accuracy was entered in the first step because of the hypothesis that mind wandering is a failure to inhibit interfering thoughts (McVay & Kane, 2010) as well as Kam and Handy (2014) findings that inhibition was negatively associated with different mind wandering indexes. Working memory and attention switching accuracy were entered in the second and third steps, respectively, based on previous findings that working memory was selectively affected by state—but not trait—mind wandering measures but that no associations were found as yet between attention switching and mind wandering frequency (Kam & Handy, 2014). The assumptions of regression analysis were tested by visual inspection of scatter plots of dependent variables against independent variables (linear relationships), scatter plots of residuals against predicted values (homoscedasticity), histograms and normal probability plots (normal distribution of residuals), using the Durbin–Watson statistic (independence of observations), calculating variance inflation factors (VIFs; multicollinearity), and computing Cook's distances (identifying influential cases). Based on power calculations (G*Power 3.1), the current linear multiple regression analysis with three predictors and a sample size of $N = 52$ would be sensitive to detect effects in between the medium and large ranges (Cohen's $f^2 = .23$), adopting a two-tailed α of .05 and a power of .80 (effects with size $f^2 = .15$ are considered medium, and effects with size $f^2 = .35$ are considered large). The regression analyses reported below, however, appeared to be able to detect small-sized effects from $f^2 = .09$ ($R^2 = .08$, $R^2_{adj} = .06$). Analyses were conducted using the statistical package SPSS Statistics (Version 24.0; IBM, Armonk, NY, USA), and α was set at .05.

Results

Measuring mind wandering in children

Correlation analyses indicated that the two measures of trait mind wandering in daily life, the ARCES and MAAS-C questionnaires, correlated highly in children (Table 1). In addition, both ARCES and MAAS-C trait mind wandering scores were positively associated with state mind wandering (as measured by the online thought probes) in the CL task but not with state mind wandering reports in the computerized EF tasks. The more likely children were to report mind wandering in everyday life, the higher their self-reported TUTs were during the CL task. All state measures of mind wandering were correlated positively independent of type of task/setting (classroom vs. computerized tasks) and time of measurement (online vs. retrospective; the latter was measured only in the EF tasks).

TUT reports occurred on 25.32% of the thought probes presented during the CL task and on 20.35% of the thought probes presented across the EF tasks (Table 1). A dependent *t* test indicated that this difference in TUT frequency between the computerized EF battery and the CL task was not statistically

Table 1
Scores on and correlations between different mind wandering measures in children.

	Mean (*SD*)	ARCES	MAAS-C	CL-TUT online	EF-TUT online	EF-TUT retro past	EF-TUT retro future
ARCES	31.03 (9.56)	–					
MAAS-C	41.67 (15.27)	.84***	–				
CL-TUT online	25.32 (26.30)	.46***	.49***	–			
EF-TUT online	20.35 (24.50)	.16	.15	.41**	–		
EF-TUT retro past	4.78 (1.96)	.23	.18	.30*	.61***	–	
EF-TUT retro future	5.29 (2.66)	.17	.14	.31*	.76***	.78***	–

Note. $N = 52$. ARCES, Attention Related Cognitive Errors Scale; MAAS-C, Mindfulness Attention Awareness Scale adapted for Children; CL, classroom listening task; TUT, task-unrelated thoughts; EF, executive function task; retro, retrospective.
* $p < .05$.
** $p < .005$.
*** $p < .001$.

significant, $t(51) = -1.29$, $p = .20$, $d = -0.19$. Children's retrospective reports of mind wandering frequency during the EF tasks showed a statistically significant higher frequency of TUTs about future events compared with past events, $t(51) = 2.15$, $p = .36$, $d = 0.20$.

Do specific EF capacities predict state measures of mind wandering?

Two outliers were identified on the flanker and attention switching tasks, respectively, and were excluded from the following analyses. The outliers were from participants with scores deviating more than 3 standard deviations from the mean on the baseline condition of the flanker task (i.e., accuracy in congruent trials) and the attention switching task (i.e., reaction time in nonswitch condition). Outliers were checked only in the (easiest) baseline conditions of these tasks because only these would be indicative of not having understood the task and/or not having executed the task properly rather than being an indication of deviant or low EF. Inclusion of these outliers did not change current results or conclusions. Mean scores (and standard deviations) in the different conditions of the EF tasks are presented in Table 2. The switching block in the attention switching task is characterized by lower accuracy and longer reaction times compared with nonswitching blocks, which is known as the so-called switching costs (e.g., Cepeda et al., 2001). Similarly, performance on the flanker task is typified by less accurate and slower responses on incongruent trials than on congruent trials (i.e., inhibition/interference costs; Eriksen & Eriksen, 1974). Only accuracy measures representing attention switching costs and flanker interference costs correlated significantly with state mind wandering measures (Table 2). Less accurate attention switching (higher attention switch costs) and worse interference control (higher flanker accuracy costs on incongruent vs. congruent trials) both were associated with higher TUTs reported retrospectively after performance of the EF tasks. Furthermore, only worse interference control (higher flanker accuracy costs on incongruent trials) was associated with higher TUT frequency during the CL task.

The three hierarchical regression models for CL-TUT online, EF-TUT online, and EF-TUT retrospective measures are presented in Table 3. EF-TUT retrospective was calculated by summing the TUT scores related to past and future events that were reported after each EF task because TUT past and TUT future reports correlated very high (Table 1) and overlapped in measured construct, and in order to decrease the number of dependent variables, and subsequently Type I errors, in the regression analyses. The assumptions of regression analysis were met; no significant influence of outliers was observed (maximum Cook's distance = 0.27; Kutner, Nachtsheim, Neter, & Li, 2005), multicollinearity was no concern because all VIF values were below 1.40 (Belsley, Kuh, & Welsch, 2005), and the errors of the main models appeared to be independent (Durbin–Watson values between 1 and 3; Field, 2009). The regression model with one or more EF variables accounted for a small but significant portion of variance in mind wandering frequency when measured online during a CL task, $F(1, 49) = 6.11$, $p = .017$, and measured retrospectively after computerized EF tasks, $F(3, 47) = 3.59$, $p = .020$, but not

Table 2
Mean scores (and standard deviations) in all EF task conditions and correlations between EF variables and state mind wandering measures.

EF task condition		*N*	*M*	*SD*	CL-TUT online	EF-TUT online	EF-TUT retro[a]
Attention switching task							
Nonswitch[b]	acc (%)	52	90.69	6.48			
	RT (ms)	51	538.26	82.61			
Switch	acc (%)	52	79.10	11.17			
	RT (ms)	51	860.91	278.93			
Switch cost[c]	acc (%)	52	11.59	9.56	$r = .06$	$r = .17$	$r = .28^{*}$
	RT (ms)	51	322.65	241.25	$r = -.18$	$r = .07$	$r = -.06$
Running span							
	acc (%)	52	59.16	23.15	$r = -.02$	$r = -.13$	$r = -.03$
Flanker task							
Congruent	acc (%)	51	77.89	14.78			
	RT (ms)	51	498.06	67.80			
Incongruent	acc (%)	51	70.26	17.64			
	RT (ms)	51	549.23	82.77			
Interference[d]	acc (%)	51	7.63	10.39	$r = .33^{*}$	$r = .15$	$r = .28^{*}$
	RT (ms)	51	51.17	43.63	$r = -.13$	$r = .14$	$r = .01$

Note. EF, executive function task; CL, classroom listening task; TUT, task-unrelated thoughts; retro, retrospective; acc, accuracy; RT, reaction time.
[*] $p < .05$.
[a] EF-TUT retro was calculated by summing the TUT scores related to past and future events that were retrospectively reported after each EF.
[b] Nonswitch scores reported are the mean scores averaged across the two nonswitch blocks.
[c] Switch cost scores for accuracy are computed by subtracting switch-acc from nonswitch-acc, and reaction time costs are computed by subtracting nonswitch-RT from switch-RT (positive scores > higher switching costs).
[d] Flanker interference scores for accuracy are computed by subtracting stimulus–response (SR) incongruent-acc from congruent-acc, and reaction time costs are computed by subtracting congruent-RT from SR incongruent-RT (positive scores > higher flanker interference).

when measured online during the computerized EF tasks (Table 3). Interference control explained 9% of the variability in children's TUT frequency reported during the CL task, whereas adding working memory and attention switching measures in subsequent steps did not explain additional variation. For the TUT frequency retrospectively reported after each EF task, interference control accounted for 6% of the variation in the initial model. Adding working memory capacity in the second step did not explain any additional variation, but switching accuracy costs uniquely accounted for approximately 8% of variability in retrospectively reported EF-TUT when added in the third step.

Discussion

The current study investigated mind wandering in typically developing 9- to 11-year-old children. More specifically, we measured and compared children's reports of mind wandering during performance of computerized EF tasks and during a classroom lesson. Furthermore, we investigated the relation between these mind wandering indexes and children's core EF capacities, namely working memory updating, attention flexibility/switching, and inhibition/interference control (Miyake et al., 2000).

First, the current results demonstrate that mind wandering occurs regularly in children during performance of computerized EF tasks and in the classroom, with children reporting TUTs on 20% and 25% of the online thought probes, respectively, in these different settings/tasks. A new aspect of this study was the assessment of children's mind wandering in an educational setting. Mind wandering frequency did not differ significantly between the classroom lesson and the computerized EF tasks. Furthermore, both online and retrospective measures of TUTs in the EF tasks were moderately positively correlated with TUTs measured online in the classroom lesson, suggesting that to some extent the same mind wandering construct was measured during controlled computerized and classroom

Table 3
Hierarchical multiple linear regression models with EF measures as predictors and state mind wandering measures as outcome variables.

CL-TUT online	Model 1 $F(1, 49) = 6.11^{*}$, $R^2_{adj} = .093$				Model 2 $F(2, 48) = 3.02$, $R^2_{adj} = .075$, $\Delta R^2 = .001$				Model 3 $F(3, 47) = 2.17$, $R^2_{adj} = .066$, $\Delta R^2 = .010$			
	B	*SE*	*β*	*t*	*B*	*SE*	*β*	*t*	*B*	*SE*	*β*	*t*
Interference costs (Flanker acc)	.84	.34	.33	2.47*	.85	.35	.34	2.45*	.89	.35	.35	2.53*
WM capacity (acc)	–	–	–	–	.03	.15	.03	0.20	.06	.16	.06	0.40
Switching costs (AST acc)	–	–	–	–	–	–	–	–	.29	.39	.11	0.73
EF-TUT online	Model 1 $F(1, 49) = 1.10$, $R^2_{adj} = .002$				Model 2 $F(2, 48) = 0.82$, $R^2_{adj} = -.007$, $\Delta R^2 = .011$				Model 3 $F(3, 47) = 0.94$, $R^2_{adj} = -.003$, $\Delta R^2 = .024$			
	B	*SE*	*β*	*t*	*B*	*SE*	*β*	*t*	*B*	*SE*	*B*	*t*
Interference costs (Flanker acc)	.35	.33	.15	1.05	.32	.34	.14	0.94	.38	.34	.16	1.10
WM capacity (acc)	–	–	–	–	−.11	.15	−.11	−0.74	−.06	.16	−.06	−0.41
Switching costs (AST acc)	–	–	–	–	–	–	–	–	.41	.38	.16	1.09
EF-TUT retro	Model 1 $F(1, 49) = 4.29^{*}$, $R^2_{adj} = .062$				Model 2 $F(2, 48) = 2.11$, $R^2_{adj} = .042$, $\Delta R^2 = .000$				Model 3 $F(3, 47) = 3.59^{*}$, $R^2_{adj} = .135$, $\Delta R^2 = .106^{*}$			
	B	*SE*	*β*	*t*	*B*	*SE*	*β*	*t*	*B*	*SE*	*β*	*t*
Interference costs (Flanker acc)	.12	.06	.28	2.07*	.12	.06	.29	2.05*	.14	.06	.34	2.50*
WM capacity (acc)	–	–	–	–	.00	.03	.01	0.09	.02	.03	.11	0.78
Switching costs (AST acc)	–	–	–	–	–	–	–	–	.16	.06	.34	2.47*

Note. $N = 51$. CL, classroom listening task; TUT, task-unrelated thoughts; acc, accuracy; WM, working memory; AST, attention switching task; EF, executive function task.
* $p < .05$.

tasks that require sustained attention/executive control such as listening to the teacher during a lesson.

The online TUT frequency of 20%, as reported by children during performance of the current EF tasks, is on the lower border of TUT percentages reported in the two previous child studies that also measured TUTs during cognitive task performance (Ye et al., 2014; Zhang et al., 2015). Such differences might be explained, however, by differences in the difficulty level of the administered cognitive tasks between studies. Studies in adults indicate that TUT frequency is generally higher in relatively simple tasks because these tasks require less cognitive resources or cognitive control capacity, thereby leaving more room for mind wandering in line with the executive control hypothesis (Smallwood & Andrews-Hanna, 2013; Smallwood & Schooler, 2006). Indeed, accuracy levels in the currently used EF tasks were quite low compared with those in the other two child studies, ranging from 59% in the working memory running span task to accuracy scores of 70–79% in the most difficult conditions of the flanker and attention switching tasks. In the study by Ye et al. (2014), a first experiment included a simple choice reaction time task in which children only responded to target stimuli appearing on 12% of the trials, leaving many cognitive resources for mind wandering on the remaining trials. Although in a second experiment the working memory load in the task was increased, the accuracy rate was still 83%, which is much higher than the accuracy rates in the current working memory task. Zhang et al. (2015) used a go/no-go task in which only the 11% of no-go trials involved executive control by requiring children to inhibit their responses. The remaining go trials required only a simple button press, also leaving a lot of room for mind wandering when compared with our EF tasks that demanded complex decisions on every trial.

Concerning the second aim of investigating relations between children's EF capacities and mind wandering, hierarchical multiple regression analyses revealed different results for the EF and classroom tasks. In the CL task, only inhibition/interference control accuracy in the flanker task explained a small (9%), but statistically significant and unique, portion of the variance in children's online self-reported TUTs. More specifically, worse inhibitory/interference control predicted higher mind wandering frequency during the classroom lesson. In the EF tasks, individual differences in EF performance did explain significant variance only in retrospective reports of (past/future-oriented) TUTs and not in online reported TUTs. More specifically, both inhibition/interference control accuracy costs (flanker task) and attention switching accuracy costs (attention switching task) explained unique variance (of 6% and 8%, respectively) in retrospectively reported mind wandering in the EF tasks, with worse inhibition and attention switching performance predicting higher TUT frequency.

To the best of our knowledge, only one previous study including adult participants has systematically examined relations between mind wandering and performance on tasks measuring the three core EFs of inhibition, attention switching, and working memory updating (Kam & Handy, 2014). In this study, mind wandering, measured during performance of the EF tasks, had detrimental effects only on inhibition and working memory performance but not on attention switching performance. However, Kam and Handy (2014) study did not explore the unique associations of each EF with mind wandering given that overlap among the three EFs was not taken into account during the analyses as it was in the current study. An individual differences study by Kane et al. (2016), executed in a large adult student sample, did take into account such associations between mind wandering and EF (but only working memory updating and inhibition/interference control) in a latent variable analysis. These authors also reported a unique relation of TUTs with an inhibition/interference control construct that was assessed by administration of multiple (types of) laboratory inhibition tasks (e.g., flanker, Stroop, go/no-go). In this latter study, TUTs were also uniquely related to a working memory updating construct, albeit less strongly than with the inhibition/interference control construct. Thus, these findings in adults and our findings in children overlap in showing a (unique) negative association between inhibitory/interference control and mind wandering, a finding that is in line with earlier suggestions that mind wandering is a failure to inhibit interfering thoughts (McVay & Kane, 2010). However, this is, to the best of our knowledge, the first study showing specific links between inhibition/interference control and mind wandering in children. The current data, furthermore, show for the first time that inhibitory/interference control capacity is a significant predictor of children's mind wandering frequency when measured in diverse situations—in controlled computerized EF tasks as well as in a classroom setting.

Working memory capacity was not a significant predictor of children's online or retrospective mind wandering reports in computerized EF tasks or in the CL task. The absence of a working memory capacity–mind wandering relation in children is in contrast to many previous individual differences studies in adults consistently reporting that adults with lower working memory capacity showed enhanced tendencies to mind wander during complex cognitive tasks such as reading and focused attention tasks (McVay & Kane, 2009; Mrazek et al., 2012; Rummel & Boywitt, 2014; Unsworth & McMillan, 2013; Unsworth & Robison, 2016) or during executive control tasks (Kane et al., 2016). Two studies that used a more similar task design to the current study by also directly measuring mind wandering during performance of attention/EF tasks did report significant relations between TUTs and working memory performance in college students even though in one study sample size was comparable to that in our study (Kam & Handy, 2014; Mrazek et al., 2012). Most of the above studies in adults, however, either included only one or two EFs (mostly working memory capacity) or did not control for overlap among all three EFs like in the current study. Furthermore, there are also adult studies that have reported no effect of individual differences in working memory capacity on online probe caught mind wandering during sustained attention or reading tasks (e.g., Jonkman, Markus, Franklin, & van Dalfsen, 2017).

Due to the relatively small sample size, one should consider the possibility that the null effects regarding the working memory–mind wandering relations in our child sample might have been caused by a lack of power to detect them. However, we do not consider this likely given that the analyses were sensitive enough to detect small-sized effects of the inhibition factor ($f^2 = .09$) and that the t values of the working memory predictor in all models were amply below the critical t value of 1.95 required to detect a medium-sized effect with the current sample size (and power of .80; G*Power 3.1). Furthermore, the additional variance explained by working memory was close to zero in all three regression models, and also the simple correlations between working memory capacity and TUTs in the CL and EF tasks were very small and nonsignificant. Thus, we consider it more likely that this discrepancy in findings regarding the role of working memory capacity in mind wandering in children versus adults is related to the delayed maturation of working memory capacity and underlying brain circuitry across childhood into adolescence (Crone, Wendelken, Donohue, van Leijenhorst, & Bunge, 2006; Huizinga et al., 2006; Schleepen & Jonkman, 2014). Such delayed maturation likely reduces the variability in working memory capacity scores and, hence, reduces the chance of finding individual differences, especially among younger children as were included in the current study. The only prior developmental mind wandering study that we know of compared adolescents and adults and reported increases in working memory capacity with age that were not accompanied by changes in mind wandering frequency (Stawarczyk, Majerus, Catale, & D'Argembeau, 2014). Thus, these findings seem to support the absence of strong working memory–mind wandering relations in childhood/adolescence, although the latter study did not compare the three different EFs as was done in the current study.

Another explanation for different EF–mind wandering relations between children and adults could be developmental differences in EF factor structure. For example, Lee et al. (2013) showed that, as opposed to the three-factor EF model in adults (Miyake et al., 2000), before 12 years of age a two-factor EF model was identified with a combined attention switching–inhibition factor and a second working memory factor. This could explain why attention switching was an additional predictor (next to inhibition/interference control) for retrospective reports of mind wandering frequency in the EF computerized tasks in our 9- to 11-year-old sample. It should be noted, however, that unique relations with attention switching were found only for children's retrospective reports of TUTs about past/future events during the EF tasks. Andrews-Hanna et al. (2013) recently stressed that thought content of mind wandering is critical when considering the costs or benefits associated with it. Although speculative, it might be that these thoughts about past/future events were more self-focused and had a stronger emotional component (or higher salience), thereby making a larger appeal on children's attention switching capacity to bring attention back to the primary task. Supporting such reasoning, a recent meta-analysis study reported unique links between rumination and attention switching (and inhibition) capacity in adults (Yang, Cao, Shields, Teng, & Lin, 2017). To test such hypotheses, future studies should include measures of the content of mind wandering in children.

Although the current measures of mind wandering did not examine the content of TUTs, the two retrospective DSSQ questions that were administered after each EF task did differentiate between the temporal orientations (past vs. future) of children's TUTs. Children reported more TUTs about future events than about past events, confirming previous findings in adults and children (Smallwood et al., 2009; Ye et al., 2014), but both indexes showed equally strong positive correlations with both children's online state and trait indexes of mind wandering.

Finally, besides state mind wandering, two measures of trait mind wandering also were collected in the current study. A very strong positive association was found between children's reports of mindlessness in daily life situations (i.e., MAAS-C) and daily attention errors due to mind wandering (i.e., ARCES), extending previous findings in adults (Carrière et al., 2008) and demonstrating the usability of these instruments in (at least 9- to 11-year-old) children. Furthermore, both trait measures were positively correlated with online probe caught TUTs during the classroom lesson, but not with online TUTs reported during EF tasks. This suggests that trait levels of mind wandering in daily life, as assessed by self-report questionnaires, are more strongly related to state mind wandering in an ecologically valid setting such as a classroom lesson than during performance of controlled computerized tasks. This can be explained by the fact that in the trait questionnaire measures one needs to reflect on mind wandering and their consequences in daily life situations that resemble more of a classroom situation. This is partly in line with the literature (Kane et al., 2017), although some studies did find associations between daily life trait and laboratory state measures of mind wandering (Seli, Risko, and Smilek, 2016; Ye et al., 2014).

In conclusion, mind wandering is very frequent in children both in controlled computerized EF tasks and in an educational setting. Although state measures of mind wandering (probe caught TUTs) in both settings/tasks were positively associated with each other, only TUTs in a classroom setting correlated positively with trait measures of mind wandering in daily life. Children's EF capacities explained a small but significant portion of variability in mind wandering frequency when measured online in a classroom lesson and measured retrospectively in computerized EF tasks. Children with lower inhibition abilities were more prone to mind wander during an educational task as well as during complex EF tasks, with the latter occurring only when mind wandering was reported retrospectively. Furthermore, worse scores on attention switching also predicted more frequent mind wandering thoughts about past/future events during performance of EF tasks (as reported retrospectively). Identifying children at risk for frequent mind wandering and developing interventions targeted at improving on-task behavior are considered relevant for educational performance (Smallwood et al., 2007).

Limitations

A first limitation of the current study is the relatively small sample size; hence, these results will need replication in a larger sample of children.

A second limitation of the current study is that it could not discriminate the intentional character of TUTs, that is, whether TUTs occurred spontaneously (i.e., unintentionally) or deliberately (i.e., intentionally). This distinction might be important given that both have recently been associated with different underlying attention mechanisms/brain networks (Golchert et al., 2017; Seli, Risko, Smilek, & et al., 2016). Future developmental mind wandering studies should make such distinctions because deliberate and spontaneous TUTs might pose different demands on the three core EFs and, thus, might show differential developmental patterns.

A third limitation of the current study might be the presentation of thought probes at approximately fixed time intervals. This might have constrained the spontaneous character of TUTs, although children were not told beforehand how many and at what time intervals thought probes would be presented. Furthermore, as in other studies with (pseudo) random probe intervals, TUTs did not decrease but rather increased with time on-task (across thought probes), which would not be expected when, over time, thought probe occurrence would have become more predictable for children.

Lastly, the current study included only a limited age sample. Future developmental studies should include a broader age sample or, preferably, should use a longitudinal design to more precisely track developmental patterns of EF and mind wandering and their associations across childhood.

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