



## Pay attention to digital text: The impact of the media on text comprehension and self-monitoring in higher-education students with ADHD



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### ABSTRACT

**Background:** Higher-education students with attention deficit hyperactivity disorder (ADHD) often face difficulties in self-regulation of learning (SRL). Studies of typical students have shown that SRL is less effective for digitally displayed texts. The current study investigated the influence of the media (digital, print) on reading comprehension and self-monitoring (a component of SRL) in higher-education students with and without ADHD.

**Methods:** Forty-five students with ADHD and 61 matched controls read an expository text displayed digitally or in print. Then, they predicted their performance score and answered comprehension questions. Sustained attention and set-shifting abilities were also assessed.

**Results:** In the digital condition, students with ADHD had significantly lower comprehension scores and were overconfident in their predictions of success relative to controls. In the print condition, the ADHD group spent more time reading the text, but their predictions of performance and comprehension scores were comparable to those of the control group. Poor sustained attention was significantly correlated with lower comprehension scores in both media conditions, whereas set-shifting correlated only with comprehension of the printed text.

**Conclusions:** Understanding a digitally displayed text is more challenging for students with ADHD than their peers, particularly when the conditions of the comprehension task favor good SRL skills.

### What this paper adds

Digital academic materials are widely available and frequently used, sometimes more than printed textbooks. How does the gradual change to digital media influence academic successes of individuals with developmental disorders? Few studies have examined this question in adults with ADHD. Even less compared comprehension of digitally displayed text to printed text. Since higher-education students are often encouraged to use computers during learning, investigating this question is of extreme importance. In this paper, we found that understanding a digitally displayed text poses a significantly greater challenge for students with ADHD relative to their typically developing peers. This group difference was not apparent when students read in print. Furthermore, the ADHD group that read the digital text was also more overconfident in their predictions of success, leading to a significantly larger calibration bias than their peers. It is important to note that these findings were under conditions that emphasized use of self-monitoring abilities, similar to those prevalent in higher education. Today, using computers to read and write assignments

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is commonplace in higher education. Thus, for students with ADHD, it is critical to support digital reading with scaffolds that specifically guide attention to self-monitoring of comprehension. Theoretically, this paper provides an initial direction of inquiry on the media effect in text comprehension and its relationship with two cognitive abilities: sustained attention and set-shifting.

## 1. Introduction

Higher-education students with attention deficit hyperactivity disorders (ADHD) represent a population at risk for academic difficulties, lower grades and higher dropout rates (Weyandt et al., 2013). The prevalence of ADHD in students attending higher education is not known. It is estimated that 2–8% of the adult population meet the criteria for ADHD (Garnier-Dykstra, Pinchevsky, Caldeira, Vincent, & Arria, 2010). Many of these students turn to learning disability centers for support in study skills and test accommodations (Wolf, 2001), though studies suggest they may need different interventions than those routinely given to students with learning disabilities (Reaser, Prevatt, Petscher, & Proctor, 2007).

Reaser et al. (2007) reported four learning-related abilities in which students with ADHD score lower than their peers with learning disabilities: managing study time, concentrating on a task (i.e. maintain and focus a relatively stable state of attention), selecting main ideas from a text, and testing strategies. All of which can be attributed to the ability to self-regulate learning, which is broadly defined as the general ability to regulate behavior and to recruit cognitive and motivational resources for the achievement of learning goals (Pellegrino & Hilton, 2012; Pintrich, 2004).

In higher-education, the need for self-regulation of learning (SRL) exists mainly outside the classroom, when in-depth reading is required to learn new knowledge and retain it in long-term memory. Awareness of one's comprehension of the text is fundamental for these goals. Reading comprehension is an ongoing mental construction process of the information presented in the text (Kintsch, 1988). During this process, the reader identifies and builds connections among text elements, such as ideas, events and facts in order to generate a coherent mental representation (van den Broek & Espin, 2012).

Metacognitive theories of SRL suggest an interaction between monitoring of reading comprehension and the control of study behavior (Dunlosky & Thiede, 1998; Nelson & Narens, 1990). In the monitoring process learners' continuously judge how well they understand and remember the study material (Greene & Azevedo, 2007). These judgements play a central role in the regulation of reading behavior aimed at filling comprehension gaps and correcting inconsistencies. Such regulatory decisions include a change in the reading strategy and allocation of additional study time to specific items (Pintrich, 2004; Tullis & Benjamin, 2011). The decision to finish studying for an upcoming test is also based on monitoring of the knowledge gained (Dunlosky & Thiede, 1998).

A robust finding is that individuals with good self-monitoring skills achieve higher scores on comprehension tests (Thiede & Anderson, 2003). When learners' prediction of future success is overestimated, they usually have poor SRL, which results in a high calibration bias (Nelson & Narens, 1990). Calibration of performance reflects the degree to which learners' predictions of future test performance (predication of performance, POP) corresponds with their actual test performance. Calibration bias represents the difference between the POP and the actual test score. Positive values of the calibration bias reflect over-confidence that can mislead a learner to premature termination of study time, which often results in lower levels of performance (Bjork, Dunlosky, & Kornell, 2013).

Individuals with ADHD, relative to typical readers are poor at monitoring their level of reading comprehension (Barkley & Murphy, 2011; Shelton, Addison, & Hartung, 2017). For instance, school children with ADHD have difficulties monitoring a series of story events and their inter-connections (Berthiaume, Lorch, & Milich, 2010), and recalling central ideas from a text (Miller, Lewandowski, & Antshel, 2013). Similarly, Yeari, Vakil, Schifer, and Schiff (2018) show that adults with ADHD have difficulties recalling central ideas from expository texts displayed on a computer screen. Recalling central ideas is associated with metacognitive skills (Schraw, 1998), and is important in the construction of a coherent mental model of the text.

### 1.1. Digital reading and self-regulation of learning

Today, there is a constant increase in the use of digital academic materials instead of printed textbooks (Siemens et al., 2015). However, the effect of the media on reading comprehension is unclear. Recently, evidence is accumulating that learning in a digital medium has a negative effect on reading comprehension and SRL, as compared to traditional printed materials (cf. Delgado, Vargas, Ackerman, & Salmerón, 2018; Singer & Alexander, 2017).

Learning on screen has been associated with less effective learning habits, lower investment of cognitive effort (LaRose, 2010), superficial levels of information processing (Wolf, Barzillai, & Dunne, 2009), and poor reading comprehension (Ben-Yehudah & Eshet-Alkalai, 2018; Delgado et al., 2018; Mangen, Walgermo, & Brønning, 2013). Ackerman and Goldsmith (2011) were the first to suggest that changes in SRL contributed to the inferior comprehension of digital text relative to printed text. Specifically, they observed that adults' learning from digital texts were over-confident in the amount of knowledge they acquired and less efficient in managing their study time. A later study suggested that inferiority of SRL in digital environments is larger in students who prefer to learn from printed materials relative to digital ones (Ackerman & Lauterman, 2012).

To the best of our knowledge there are very few studies that compared print to digital reading comprehension, within the same study, in individuals with ADHD. Two studies in school-age children with ADHD found better comprehension for texts displayed on a computer screen relative to print. Stern and Shalev (2013) reported that reading comprehension of adolescents with ADHD was better on screen with extra line-spacing than on paper. Shaw and Lewis (2005) found improvements in learning outcomes when primary school children with ADHD performed a science task on a laptop computer relative to on paper, but only when the text was presented without distracting animations. Notably, in both studies the text was available when participants answered the comprehension

questions. This procedure allowed children to look-back at the text, which does not encourage SRL during text reading.

### 1.2. Sustained attention and set shifting in ADHD

Reading comprehension difficulties in children and adolescents with ADHD have been reported in the literature irrespective of the text media. Possible explanations for these difficulties include poor sustained attention (Stern & Shalev, 2013) and deficits in executive functions such as set shifting (e.g., Martinussen & Mackenzie, 2015).

Sustained attention is the ability to maintain and focus a relatively stable state of attention on a task, over an extended period of time. Individuals with poor sustained attention have elevated levels of attentional lapses, in which attention wanders from the intended task to environmental distractors or irrelevant thoughts. Such lapses in attention are not unique to individuals with attentional deficits. However, they are more frequent in ADHD and usually go unnoticed (Smallwood, Fishman, & Schooler, 2007). Attentional lapses shift the reader's attention away from construction of the text's mental representation and from story events relevant to its updating, which is likely to have a negative influence on comprehension (Smallwood et al., 2007).

Executive functions are a set of domain-general skills that refer broadly to the ability to inhibit irrelevant information, to shift between tasks or mental sets and to maintain and update task relevant information (Miyake et al., 2000). In the current study we focused on the ability to shift between mental sets, also referred to as task-switching or cognitive flexibility (Diamond, 2013). This ability is strongly correlated with reading comprehension (e.g., Cartwright et al., 2016; Kieffer, Vukovic, & Berry, 2013; Yeniad, Malda, Mesman, Van Ijzendoorn, & Pieper, 2013). Studies aimed at understanding the contribution of shifting to the process of reading regulation suggest that it plays a role in shifting attention between the learned material and the metacognitive processes (Kieffer et al., 2013), and in the flexible use of different reading strategies to accomplish reading goals (Georgiou & Das, 2016). Unlike sustained attention deficits that are prevalent in individuals with ADHD (Tsal, Shalev, & Mevorach, 2005), studies that examined shifting impairments in this population have shown mixed results (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005).

### 1.3. The current study

In the current study, we examined the influence of text media on reading comprehension among higher-education students with and without ADHD. We investigated text comprehension under conditions that are common in higher education and favor good self-monitoring skills; namely, unlimited study time and absence of study materials during testing. We hypothesized that, among students with ADHD who often face self-monitoring difficulties (Shelton et al., 2017), the previously established link (e.g., Ackerman & Goldsmith, 2011) between poor SRL and inferior comprehension of digital text will be exacerbated.

In addition, as individual differences in attentional and executive functions exist in the ADHD population (Dobson-patterson, Gorman, Chan, & Shum, 2016), we further explored the influence of the media on the relationships between reading comprehension and performance on tasks previously correlated with reading comprehension: sustained attention (Stern & Shalev, 2013) and set-shifting (Kieffer et al., 2013). We hypothesized that the relationships among reading comprehension and these cognitive factors would be independent of text media.

## 2. Methods

### 2.1. Participants

A total of 106 higher-education students participated in the study for monetary compensation. Participants were recruited through social media, using ads posted in groups for higher-education students. The ads targeted either adults with clinical diagnosis of ADHD or the general student population. Potential participants were phone screened by a research project coordinator to determine their match to the study's criteria. General inclusion criteria were: no diagnosis of reading disabilities, normal or corrected vision, and a native-speaker of Hebrew. Those that self-reported a clinical diagnosis of ADHD were asked to bring an up-to-date clinical evaluation on the day of testing. Following this screening procedure, 45 participants meet the criteria for a clinical diagnosis of ADHD based either on DSM-IV or DSM-V criteria (16 males and 29 females, mean age: 25 years, SD: 4). Sixty-one participants in the control group had no reported history of ADHD, (13 males and 48 females, mean age: 25 years, SD: 4). To confirm assignment to ADHD or control group, all of the participants completed the Conjunctive Continuous Performance Task (CCPT, see Section 2.2.2).

### 2.2. Materials

#### 2.2.1. Reading comprehension task

The reading comprehension task consisted of an expository text (adapted from a website) on the importance of a warm-up before an athletic activity, and a comprehension test. The task was validated in previous studies that compared reading comprehension in print and digital media (Ackerman & Goldsmith, 2011; Ackerman & Lauterman, 2012). The text consisted of 1200 words and 3 colored pictures illustrating information from the text on warm-up exercises. It was displayed in 12 pt. David font, with double spacing between lines. The layout of the text and pictures were identical in the digital and print conditions. In the digital condition, the text was displayed in Adobe Reader on a 19" screen of a desktop computer. Participants were instructed to use the page down button to advance through the text.

The comprehension test included 10 multiple-choice questions with 4-AFC answers. Five literal questions were on memory for

details (e.g. "what should not be included in a warm up before a moderate exercise?"). These were intermixed with five inferential questions requiring higher order comprehension (e.g. "what is the optimal warm-up procedure?"). For further details on the reading task see [Ackerman and Goldsmith \(2011\)](#). In the present study, the internal reliability of the comprehension questions was reasonable for this number of items (Cronbach's alpha: .62).

### 2.2.2. Sustained attention task

The ability to sustain attention over time was measured in the visual modality using a computerized task developed and validated by [Tsal et al. \(2005\)](#). Participants were presented with an experimental block of 320 stimuli that included all possible combinations of four shapes and four colors. They were instructed to press a space bar as quickly as possible when the target stimulus appeared (a red square). The target item appeared on 30% of the trials (for further details see [Tsal et al., 2005](#)).

Four dependent measures were computed ([Tsal et al., 2005](#)) based on response latencies and accuracy: a. Mean response time (RT) of correct responses; b. Task score, which is based on the standard deviation (SD) of RT for correct responses divided by the participant's mean RT for correct responses. This computation is performed to minimize the overall effect of slow responders; c. Omissions is the percent of missed responses to the target; and d. Commissions is the percent of false identifications of the stimulus as target. High values on these four measures reflect poor ability to sustain a constant level of attention over time.

### 2.2.3. Set-shifting task

The ability to shift between mental sets was measured with a computerized switching task developed and validated by [Meiran \(1996\)](#). An empty 2-by-2 grid (i.e., four adjacent squares) was presented in the center of the screen. On each trial the target stimulus (a black square) appeared in one of the quadrants. Participants reported the position of the target stimulus according to the discrimination task they were cued to perform. In the vertical task, the position of the target was along the vertical axis, participants made an up-down discrimination. In the horizontal task, the position of the target was along the horizontal axis, correspondingly participants made a right-left discrimination. An instructional cue (arrowheads), at the beginning of each trial, indicated which discrimination task to perform. The task had three blocks with a short break in between each block. The first two consecutive blocks had randomly intermixed trials of the two discrimination tasks, 140 trials per block. In the third block participants performed a single-task – the "pure block", 70 trials (for additional details see [Meiran, 1996](#)). The dependent variable was reaction time (RT) for correct trials. Two RT measures were calculated from the data: a. mixing cost - the difference in RT between the mixed blocks and the pure block, and b. switch cost – the difference in RT between switch and non-switch trials, only in the mixed blocks. Trials with RTs longer than 2000 ms were excluded from the analyses. To ensure enough correct trials per condition, participants who scored less than 75% correct on the most difficult condition (task switching and incongruent stimulus-response) were excluded from the analysis. (For further details see [Meiran, 1996](#)). This strict criterion led to the exclusion of 40 participants (18 controls and 22 ADHD) from analyses that involved the set-shifting task.

### 2.2.4. The adult reading questionnaire

ADHD has a high rate of comorbidity with developmental dyslexia. To rule out the possibility of undiagnosed reading disorders in the ADHD group, we administered the Adult Reading Questionnaire (ARQ, [Snowling, Dawes, Nash, & Hulme, 2012](#)), a self-report questionnaire for adults on reading and related abilities. The ARQ was translated to Hebrew and validated in a previous study (ARQ-Hebrew, [Ben-Yehudah & Gilutz, 2018](#)). It includes 15 self-report questions that assess reading and language abilities associated with dyslexia. The items address the severity and frequency of 'symptoms' of dyslexia, such as difficulties reading aloud, reading new words and spelling, as well as word finding problems (e.g., "do you find it difficult to find the right word to say"). Responses to the majority of the questions are on a 5-point Likert scale (0–4 scores) and some are yes/no/maybe (or don't know) questions (respectively, 4, 0 or 2). We calculated two indices from subsets of questions that addressed a specific ability category: reading (ARQ-reading) and word finding (ARQ-Word finding). Higher scores indicate more severe difficulties in the set of skills associated with a category. The maximum score of each index is noted in [Table 1](#). Further details appear in [Snowling et al. \(2012\)](#). The internal

**Table 1**

Mean and SDs for background measures, shown separately for each group by text medium. One-way ANOVA for the comparison between groups.

	Group								One-way ANOVA	
	ADHD				Control					
	Digital		Print		Digital		Print		F	p
M	SD	M	SD	M	SD	M	SD			
Age (years)	24.7	3.9	26.2	4.2	26	4.8	24.7	2.3	1.24	.30
Use of digital devices <sup>1</sup>	1.9	1.6	2.2	1.1	2.5	1.2	2.7	1.3	.17	.17
Prior topic knowledge <sup>1</sup>	2.9	1	2.9	.9	2.9	1	2.8	1	.13	.94
ARQ <sup>2</sup> -Reading (max 20)	9.1	2.6	10.7	3.4	9.5	1.7	10.4	2.25	2.29	.09
ARQ <sup>2</sup> -Word finding (max 12)	8.5	1.6	8.3	3.0	8.6	2.2	8.9	1.6	.32	.80

Note. 1. A composite measure, scale 1–5 (see [2.2.5](#) for details). 2. Raw scores for the Adult Reading Questionnaire (see [2.2.4](#) for details on each index). Maximum score is noted in parentheses, with higher scores indicating more severe difficulties.

reliability of the reading (Cronbach's alpha: .81) and word finding (Cronbach's alpha: .82) indices was high.

2.2.5. Demographic questionnaire

The demographic questionnaire includes a set of standard demographic questions on participants' age, gender and educational background, as well as a set of questions on everyday use of digital devices. For example: frequency of using e-mail, social networks, and the Internet to search for information during work, study and leisure time. Responses were on a 5-point Likert scale (1 = very little, 5 = very often). A composite score (i.e. use of digital devices) was calculated as the mean of the responses to questions on daily use of digital devices. The questionnaire also has 3 questions to assess participants' previous knowledge of the topic in the comprehension task (5-point Likert scale) and a question about preferred media for reading academic materials.

2.3. Procedure

2.3.1. General procedure

The study was administered in groups of up to eight participants in a quiet computer lab. We used a 2-by-2 between-groups experimental design, with text medium (print, digital) and attentional group (ADHD, control) as the independent variables. In the digital condition: 21 students with ADHD and 26 controls. In the print condition: 24 students with ADHD and 35 controls. Participants were quasi-randomly assigned to a test session, in which all of them read the text in the same media. Participants with ADHD were instructed not to take their medication for ADHD symptoms on the day of testing. All tasks and questionnaires were administered in a two-hour session that included a short mandatory 10-minute break. Each participant completed four tasks in the same order: a. set-shifting, b. reading comprehension, c. sustained attention, d. ARQ-Hebrew questionnaire and e. demographic questionnaire. A short break was given after the reading comprehension task.

2.3.2. Reading comprehension task

Participants read the text silently with no time constraints. They were instructed to read the text carefully until they felt that they understood the material and were ready to answer comprehension questions on the topic. Participants were informed that the text would not be available while they answered the questions. After they finished reading the text and before viewing the test questions, participants predicted their score on the comprehension test, on a scale from 0 to 100% (aka, Prediction of Performance, POP). Then the text was removed, and they were presented with 10 multiple-choice 4-AFC comprehension questions. The dependent measures were a. reading comprehension accuracy, b. reading duration - time spent reading the text, c. calibration bias - difference between participants' predictions of their future test performance and their actual test score (between 0–100%). Higher values of calibration bias indicate overconfidence in knowledge acquired during reading. Participants in both conditions answered the comprehension questions on a desktop computer.

3. Results

3.1. Comparisons between the ADHD and control groups

3.1.1. Background measures

Descriptive statistics for the background measures are shown in Table 1, separately for each group by text medium: ADHD-digital, ADHD-print, control-digital and control-print. The groups did not differ in their mean age, daily use of digital devices and prior knowledge on the topic of the comprehension test. Importantly, they did not differ in their self-report of reading and related language abilities, as assessed by the ARQ-Hebrew questionnaire.

3.1.2. Performance on the sustained attention and set-shifting tasks

Performance of the control and ADHD groups were compared on the sustained attention and set-shifting tasks (Table 2). Note that the number of participants included in the analysis of the set-shifting task was relatively smaller than that of the sustained attention

Table 2

Mean performance and SD on the sustained attention and set-shifting tasks, separately for the control and ADHD groups. T-tests and effect sizes for the comparison between the two groups.

	Control		ADHD		t-test		
	M	SD	M	SD	t	p	Cohen's d
<b>Sustained attention</b>	(n = 58)		(n = 43)				
Mean RT of correct responses (ms)	442.99	45.66	475.63	65.63	-2.95	.004	.58
Task score	.14	.03	.16	.05	-2.19	.003	.48
Omissions (%)	.000	.01	.03	.07	-2.99	.03	.42
Commissions (%)	.02	.04	.02	.05	-.54	.99	.09
<b>Set shifting</b>	(n = 43)		(n = 23)				
Switch cost (ms)	100	107	79	76	.85	.4	.2
Mixing cost (ms)	299	132	266	149	.86	.39	.22

**Table 3**

Means and SDs for reading comprehension, prediction of performance, calibration bias and reading time, shown separately for each media condition by group.

Text medium	Digital				Print			
	Control (n = 26)		ADHD (n = 21)		Control (n = 35)		ADHD (n = 34)	
	M	SD	M	SD	M	SD	M	SD
Reading comprehension (%)	75	11	61	21	72	15	71	17
Prediction of performance (%)	88	6.6	83	9	82	8.8	82	9.3
Calibration bias (%)	5	9	20	20	10	14	10	20
Reading time (min)	11.5	2	12.8	5	11.9	4	14	4

task because of a stricter exclusion criterion (see Section 2.2.3). In particular, the sample size of the ADHD group was considerably reduced relative to that of the control group.

Table 2 shows that the ADHD group was significantly worse than controls on the following measures of sustained attention: mean RT of correct responses,  $t(99) = -2.95$ ,  $p < .005$ ,  $d = .58$ ; task score,  $t(99) = -2.19$ ,  $p < .005$ ,  $d = .48$ ; omissions,  $t(99) = -2.19$ ,  $p < .05$ ,  $d = .42$ . No significant difference was observed for commissions,  $t(99) = -.54$ ,  $p = .59$ ,  $d = .01$ . The mean percent of omission and commission errors in both groups was very low, as expected for adults (Shalev, Ben-Simon, Mevorach, Cohen, & Tsai, 2011).

In contrast, there were no significant differences between the ADHD and control groups on the measures of the set-shifting task: switch cost,  $t(64) = .85$ ,  $p = .4$ ,  $d = .2$  and mixing cost,  $t(64) = .86$ ,  $p = .39$ ,  $d = .22$ .

### 3.1.3. Reading comprehension, prediction of performance and text medium

Two-way analyses of variance (ANOVA) were conducted to assess the main effects and interactions between text medium (digital, print) and group (ADHD, control) on the 3 measures of the comprehension task and on calibration bias. Descriptive statistics for each dependent variable are shown in Table 3, separately for each group.

There was a significant main effect of group on accuracy in the reading comprehension task, with better performance of the control group as compared to the ADHD group,  $F(1,102) = 4.5$ ,  $p < .05$ , partial  $\eta^2 = .04$ . There was no main effect for text medium on comprehension accuracy,  $F(1,102) = .79$ ,  $p = .3$ , partial  $\eta^2 = .01$ . However, there was a significant interaction between group and text medium,  $F(1,102) = 4.5$ ,  $p < .05$ , partial  $\eta^2 = .04$ . Planned  $t$ -tests revealed that in the digital condition the ADHD group had significantly lower reading comprehension scores as compared to the control group,  $t(45) = 2.9$ ,  $p < .005$ ,  $d = .8$ . There were no significant differences between the two groups in the print condition,  $t(57) = .14$ ,  $p = .88$ ,  $d = .09$ .

There were no significant differences among the four groups in their predictions of success rate (range 82–83%) on the comprehension test (see POP measure in Table 3), all  $F$ s  $< .4$ ,  $p > .5$ . Calibration bias was then calculated as the difference between participants' POP and their actual scores, with higher values indicating overconfidence in their success on the comprehension score.

For the measure of calibration bias, there was a similar pattern of main effects and interaction between text medium and group. Namely, there was a significant main effect for group,  $F(1,101) = 4.69$ ,  $p < .05$ , partial  $\eta^2 = .04$ . There was no effect for text medium,  $F(1,101) = .54$ ,  $p = .46$ , partial  $\eta^2 = .06$ . But there was a significant interaction effect,  $F(1,101) = 6.09$ ,  $p < .01$ , partial  $\eta^2 = .06$ . The interaction effect resulted from the larger overconfidence of the ADHD group in the digital condition,  $t(44) = -3.3$ ,  $p < .001$ ,  $d = .95$ . In the print condition there was no significant difference between the two groups  $t(57) = .21$ ,  $p = .8$ ,  $d = .05$ .

It is important to note that these differences in reading comprehension and calibration bias were not due to group differences in a preference for reading in one medium or another, not for a comparison of the ADHD and the control group,  $\chi^2(1) = .02$ ,  $p = .89$ , nor for a comparison between the print and the digital group,  $\chi^2(1) = .44$ ,  $p = .51$ . Also, there were no significant differences between the mean POP of the ADHD group (mean: 82.6, SD: 9.1) and the control group (mean: 82.3, SD: 9.0),  $t(104) = .192$ ,  $p = .85$ ,  $d = .04$ , nor between the print (mean: 82.0, SD: 8.2) and digital (mean: 83.0, SD: 7.7) groups,  $t(104) = .63$ ,  $p = .53$ ,  $d = .13$ .

An analysis of the time spent by each group reading the text revealed a significant main effect of group,  $F(1,101) = 3.98$ ,  $p < .05$ , partial  $\eta^2 = .04$ . The ADHD participants invested more time reading the text as compared to the control group. Successive  $t$ -tests showed that the group differences were more pronounced in the print condition where they approached significance,  $t(57) = -1.93$ ,  $p = .08$ ,  $d = .48$ . In the digital condition, there was no significant difference among the groups,  $t(44) = -1.08$ ,  $p = .29$ ,  $d = .29$ .

### 3.2. Sustained attention, set shifting and comprehension

There were significant negative correlations between reading comprehension scores and measures of sustained attention ability in both the print and digital conditions (Table 4). Namely, a reduced level of sustained attention (expressed by higher values) was associated with lower comprehension scores. In the set-shifting task, there were significant correlations between reading comprehension in the print condition and the switch and mixing cost measures. Higher costs were associated with lower comprehension scores.

**Table 4**

Correlations between performance measures: reading comprehension accuracy, sustained attention task score and omission rate, switch and mix costs in set shifting task; shown separately for print and digital conditions. Only significant correlations are noted, in parenthesis are the number of participants.

		1.	2.	3.	4.	5.
<b>Print condition</b>						
	1. reading	1				
Sustained Attention (56)	2. task score	-.35**	1			
	3. omissions	-.40**	.62**	1		
Set Shifting (33)	4. switch cost	-.60**			1	
	5. mix cost	-.45**			.57**	1
<b>Digital condition</b>						
	1. reading	1				
Sustained Attention (45)	2. task score	-.41**	1			
	3. omissions	-.32*	.45**	1		
Set Shifting (33)	4. switch cost				1	
	5. mix cost				.40*	1

\*  $p < .05$ .

\*\*  $p < .01$ .

**4. Discussion**

This study examined the influence of the media (i.e., media effect) on cognitive and metacognitive factors, respectively, reading comprehension and prediction of performance (POP), in two populations that differed in the severity of attentional difficulties. Specifically, we compared performance across four groups of higher-education students: with and without ADHD, who read on screen (digital condition) or on paper (print condition). In addition, the relationships among sustained attention, set shifting and reading comprehension were investigated separately for each medium.

In line with our hypothesis, there was a significant interaction effect between group and reading medium for both text comprehension and calibration bias. However, effect sizes were low due to the broad range of comprehension abilities in our population. Follow-up tests revealed a significant group difference only in the digital condition, in which ADHD participants had lower comprehension scores than their peers without ADHD. Despite the lower performance of the ADHD group in the digital condition, their predictions of success were similar to those of the other groups. This resulted in a large calibration bias, namely overconfidence in their comprehension ability.

Another indication of overconfidence in the ADHD group was the smaller amount of time they spent reading the digital text relative to that spent by the ADHD group who performed the task in print (Dunlosky & Rawson, 2012). Overall, students with ADHD invested more time reading the text relative to control students, but the group difference was largest in the print. This result further supports the hypothesis that self-monitoring was better when learning occurred on paper than digitally. We speculate that the prolonged study time in print had a positive effect on learning, as the ADHD group matched the control group in their reading comprehension scores and calibration of learning.

**4.1. Sustained attention set shifting and reading comprehension**

The marked heterogeneity in executive functions and attentional abilities, which characterizes the ADHD population, may be central to the variability we observed in self-monitoring and reading comprehension. Such individual differences in cognitive abilities may account for the media effect in reading comprehension. For instance, a digital display may exacerbate existing difficulties sustaining attention for prolonged periods of time. On the other hand, a digital display could interfere with shifting of attention between main ideas in the text, and between text content and metacognitive monitoring. These explanations are not mutually exclusive.

We ran a set of correlation analyses as a first step in examining these explanations for relationships between reading comprehension scores and individual differences in sustained attention and in set shifting abilities. Performance on the sustained attention task was moderately correlated with comprehension scores in both media conditions, consistent with previous findings (Stern & Shalev, 2013). Miller et al. (2013) suggested that children with ADHD allocate more cognitive resources to maintaining attention on task, thus, effectively limiting their resources available to form connections between ideas in the text. One way to compensate for lower attentional resources is to allocate more time to studying the text. Consistent with this strategy, we found a prolonged study time in ADHD participants who read on paper as compared to the other groups. This may have, to some extent, compensated for their comprehension difficulties.

Performance on the set-shifting task was strongly correlated with reading comprehension, but only in the print condition ( $r = -.6$ ). This finding is consistent with results from previous studies in school-age children that assessed reading abilities with standardized tests administered on paper. For example, Kieffer and colleagues tested 4<sup>th</sup> grade students using a standardized printed reading comprehension test (Gates-MacGinitie Reading test) and a known measure of set shifting (Wisconsin Card Sorting task). They found a direct association between shifting ability and reading comprehension, as well as indirect associations through language

comprehension and word reading ability (Kieffer et al., 2013, see also Martinussen & Mackenzie, 2015). In a meta-analysis that examined the association between children's shifting ability and academic achievement, Yeniad et al. (2013) reported a significant association between these abilities. It is noteworthy that this meta-analysis did not report the medium in which studies administered their academic tests; probably because researchers have not considered this aspect of test administration and its possible influence on academic achievements.

In contrast to our hypothesis, we did not find a correlation between reading comprehension assessed digitally and set shifting ability. However, such a relationship cannot be ruled out because we used a strict criterion to analyze the data from the set-shifting task. This criterion led to the exclusion of 49% of the data from the ADHD group and 29% of the data from the control group. The exclusion of such a high portion of the data limits our ability to draw conclusions from a null finding. Possibly, excluded participants had a greater difficulty inhibiting prepotent responses, which resulted in their high error rates and exclusion from the data set. Interestingly, correlations between inhibition ability and reading comprehension, assessed with standardized tests in print, have been reported in the literature (e.g. Borella, Carretti, & Pelegrina, 2010). But, to our knowledge, the association between inhibition ability and digital reading comprehension has not been examined.

Taken together, these findings are consistent with the explanation that reading on screen is associated with more cognitive effort than reading on paper, which leads to a reduction in resources available to understand texts (LaRose, 2010). This depletion of cognitive resources is particularly harmful for individuals with ADHD, whose inherent attentional difficulties draw resources away from text processing.

#### 4.2. The media effect and attentional deficits

To date, very few studies have examined the media effect in reading comprehension for populations with disabilities that affect their academic achievement. Two studies that investigated this question in children with ADHD found positive effects of the digital medium on reading comprehension. In a study of adolescents with ADHD, Stern and Shalev (2013) found increases in reading comprehension scores when the text was presented digitally with large spacing between lines as compared to a similar layout in print. Shaw and Lewis (2005) reported better learning outcomes for primary school children with ADHD when a science task was completed on a computer-mediated workbook relative to a paper version of this workbook. Our results are not consistent with these previous findings, as we found an opposite pattern of results - decrements in performance when the comprehension task was administered digitally relative to assessment on paper.

Several methodological differences between our study and previous studies could explain this opposite pattern of findings. First, the need for self-monitoring of learning was larger in our comprehension task than in the previous studies (Shaw & Lewis, 2005; Stern & Shalev, 2013), due to task features that called for more metacognitive processing. Second, the age of the populations sampled across studies was very different.

Three features of our reading comprehension task induced a greater reliance on metacognitive skills for a successful outcome: text length, task instructions and text availability during the comprehension test. First, we used a relatively long text (1200 words) that required the learner to regulate reading time and use reading strategies. Second, the task instructions were rather vague: "read until you feel ready to answer a set of comprehension questions", which is known to promote more self-monitoring of understanding. Third, when participants answered the comprehension questions the text was not available to them. Text availability has been shown to be an important factor in text processing and reading regulation (Ferrer, Vidal-Abarca, Serrano, & Gilabert, 2017). For example, when readers know in advance that the text will not be available during testing; they reread the text more often. In contrast, availability of the text while answering the comprehension questions promotes more task-oriented reading.

In contrast to these methodological considerations of our study, Stern and Shalev (2013) gave participants short texts (approximately 300 words) and instructed them to read the text only once. Moreover, their participants were allowed to look back at the text when they answered the open-ended comprehension questions. Thus, the comprehension questions could serve as scaffolds for the learning process, so it was not necessary to regulate learning time or use higher order reading strategies. Similarly, Shaw and Lewis (2005) had children perform a series of science tasks, in which short texts and follow-up questions were presented in close proximity. This setup also provides external scaffolds for learning and the text is available throughout the task. Taken together, these studies suggest that presenting a reading task on a computer screen may improve outcomes for learners with ADHD, but only under conditions that direct the learning process and offer scaffolds for text comprehension.

Further support for this conclusion comes from two studies that examined reading comprehension in higher-education students with ADHD. In each study comprehension was assessed in a different media, either digitally (Lewandowski, Gathje, Lovett, & Gordon, 2013) or in print (Miller, Keenan et al., 2013). Both studies used short passages, constraints on study-time and provided the text when participants answered comprehension questions. Accordingly, neither study found differences in reading comprehension between ADHD and age-matched control groups. These results support our conclusion that under task conditions that do not require a high-level of metacognitive skills (specifically self-monitoring) the media effect diminishes.

The second methodological difference between our study and those discussed above was the age of the population sampled by each study. In the previous studies school-age children were tested, adolescents (Stern & Shalev, 2013) and primary school children (7–12 years old, Shaw & Lewis, 2005). In contrast, we tested adults that attended higher-education institutes. Adult readers have more reading experience and a stable set of reading strategies that they use to understand long academic texts. These age differences might interact with the text's medium, as well as with its length and difficulty, to produce different patterns of results for the media effect in reading comprehension. Moreover, although participants in our study did not have media preferences, it is likely that during their literacy development they had more experience with printed text and thus more opportunities to develop strategies for this type

of reading material. School-children today are much more proficient in reading digital texts (albeit short ones). Thus, their reading experiences may be very different from the population we sampled (data collected in 2016). Future studies should follow-up on the complex set of potential interactions between sample age, reading experience in different media and task features.

It is worth noting that inferiority of digital reading comprehension observed in our study for adults with ADHD is similar to that seen in other studies of populations without attentional deficits. The superficial nature of digital reading comprehension has been noted by many studies (e.g., Ben-Yehudah & Eshet-Alkalai, 2018; LaRose, 2010; Mangen et al., 2013), as well as an inferiority in metacognitive processing when dealing with digital text (e.g., Ackerman & Goldsmith, 2011; Sidi, Shpigelman, Zalmanov, & Ackerman, 2017). Thus, our findings for students with ADHD are not surprising when taking into account previous results for typical adult populations.

#### 4.3. Limitations and future directions

While contemplating the implications of this study, it is important to consider its limitations. We used a self-report questionnaire to assess the reading and related language abilities of our sample. Although such questionnaires are not as reliable as objective measures of cognitive abilities, it has been shown that responses on this particular questionnaire can be used as a valid measure of literacy skills (Snowling et al., 2012). If possible, it is wise to include an objective measure of language and literacy skills, since disorders in these areas often overlap with ADHD (Martinussen, 2015). Another limitation of our study was the selection bias resulting from our sampling method, adults who attended higher-education institutes. The ADHD sample consisted of individuals who decided to pursue post-secondary education and were accepted to such institutes. Thus, it is likely this population had relatively good learning abilities that could compensate for their attentional disorder. It is important that future studies investigate the media effect in more diverse ADHD populations, as well as consider reading experience and task features, as possible moderators of the media effect in reading comprehension.

## 5. Conclusion

The findings of the current study suggest that, under task conditions that favor good metacognitive skills, specifically self-monitoring, learning from digital texts leads to inferior reading comprehension for students with ADHD relative to their peers without ADHD. Further studies are needed to understand the range of factors that influence the relationship between attentional abilities and reading comprehension in both print and digital media. As the use of digital academic texts is constantly increasing, it is important to investigate ways to improve self-monitoring during technology-enhanced learning, and to explore interventions that will enable students with ADHD to benefit from the affordances of learning with technologies.

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