Learning and Instruction 61 (2019) 138–147

Contents lists available at ScienceDirect

Learning and Instruction

journal homepage: www.elsevier.com/locate/learninstruc

Do students learn better when seated close to the teacher? A virtual classroom study considering individual levels of inattention and hyperactivity-impulsivity

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ARTICLE INFO

Keywords:
Virtual reality
ADHD symptoms
Learning
School

ABSTRACT

This study investigated whether students in grades 5 and 6 learned better when seated proximally to the teacher during a virtual classroom math lesson, taking individual levels of inattention and hyperactivity-impulsivity (i.e., ADHD symptoms) into account. In general, students learned better in the proximal seat location compared to a distant one. Additionally, more intense symptom levels impaired learning more. When considering individual levels of ADHD symptoms, students' learning outcomes did not specifically benefit from a proximal seat location. Consequently, the present study did not support the general assumption that a proximal seat location fosters academic achievement in students experiencing individual levels of inattention and hyperactivity-impulsivity.

1. Introduction

Every student does not pay attention, is overly active, or acts impulsively at times, and hence sometimes exhibits behavior subsumed under the term ADHD[1] symptoms (APA, 2013; DeYoung & Rueter, 2017; DuPaul & Stoner, 2014; Levy, Hay, McStephen, Wood, & Waldman, 1997). Inattention refers to a generalized absent-mindedness or failure to pay close attention to details that is expected to emerge from a lack of effortful attention control (APA, 2013; Martel, Nigg, & von Eye, 2008). Hyperactive-impulsive behaviors are hectic, lack conscious control, and incorporate a high level of physical activity (APA, 2013). They are assumed to serve to constantly redirect an individual's attentional focus to novel or more salient stimuli, due to an inability to control immediate incentive and affective responses (Martel et al., 2008). However, whereas all students experience these symptoms at times, the majority should experience them at clinically insignificant intensity levels (DuPaul, Gormley, & Laracy, 2017; Lubke, Hudziak, Derks, van Bijsterveldt, & Boomsma, 2009; Polderman et al., 2007). Only a small minority of students - approximately five percent - are diagnosed with ADHD, and hence experience clinically significant symptom levels (Polanczyk, de Lima, Horta, Biederman, & Rohde, 2007).

1.1. ADHD symptoms and academic achievement

Substantial evidence supports the assumption that inattentive and hyperactive-impulsive behaviors impair the ability to focus on relevant aspects of one's environment, including in academic contexts (Kofler, Rapport, & Matt Alderson, 2008; Martel et al., 2008; Spira & Fischel, 2005). Hence, individual ADHD symptom levels should impair academic functioning (Coghill & Sonuga-Barke, 2012; DuPaul & Stoner, 2014; Merrell & Tymms, 2001). Substantial empirical evidence demonstrating that ADHD symptoms generally impair academic functioning at all levels of the intensity continuum supports this

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[1] attention-deficit/hyperactivity disorder (ADHD); American Psychiatric Association (APA); interstimulus interval (ISI); response time (RT).

https://doi.org/10.1016/j.learninstruc.2018.10.004
Received 22 September 2017; Received in revised form 21 September 2018; Accepted 22 October 2018
Available online 10 November 2018

expectation. ADHD symptoms have been shown to be associated with poorer test performance, poorer grades, higher grade retention rates, and more frequent referral to special education services (Barry, Lyman, & Klinger, 2002; Biederman, Faraone, Milberger, & Al, 1996; DuPaul & Stoner, 2014; Jensen et al., 2004; LeFever, Villers, & Morrow, 2002; Loe & Feldman, 2007; Polderman, Boomsma, Bartels, Verhulst, & Huizink, 2010). Moreover, they have been shown to be associated with an increased risk of leaving school without a qualifying degree and with lower overall occupational attainment in adulthood (Mannuzza, Klein, Bessler, Malloy, & LaPadula, 1993). Hence, ADHD symptoms can impair academic functioning as well as an individual's life course development.

1.2. Fostering academic achievement in school

When students experience academic impairment as a function of their ADHD symptom levels, teachers can draw on a wide variety of classroom management techniques believed to promote academic achievement in addition to more specific intervention programs (DuPaul & Stoner, 2014; Gaastra, Groen, Tucha, & Tucha, 2016; Mackowiak & Schramm, 2016; Pfiffner & Barkley, 1998). Usually, these techniques can be implemented without an ADHD diagnosis; it is up to the teacher's discretion,[2] meaning that students with clinically insignificant levels of ADHD symptoms may also benefit from them. These classroom management techniques generally aim to organize classrooms in ways that minimize the time spent dealing with disciplinary problems and other classroom interruptions, thereby maximizing the time available for student learning (Hamre & Pianta, 2010; Wang, Haertel, & Walberg, 1993). Many elements of classroom management aim to foster desirable and prevent undesirable behaviors (e.g., clear rules, regulatory measures; Emmer & Stough, 2001).

Some of these elements specifically concern how classrooms' physical aspects, such as the arrangement of desks and students' seat locations, may improve classroom management (MacAulay, 1990; Wannarka & Ruhl, 2008). Teachers have been shown to generally prefer arranging desks in small groups when seeking to foster cooperation among students, such as during group work (Gremmen, van den Berg, Segers, & Cillessen, 2016). In contrast, they prefer an arrangement in rows during independent seatwork to foster concentration. The latter arrangement might be especially supportive of concentration among students experiencing difficulties paying attention. Empirical evidence supports teachers' views, revealing that small-group arrangements indeed foster interaction among students, and hence on-task behavior during group work (MacAulay, 1990; Rosenfield, Lambert, & Black, 1985; Wannarka & Ruhl, 2008). In contrast, arrangements in rows foster on-task behavior during independent seatwork (Bennett & Blundell, 1983; Hastings & Schwieso, 1995; MacAulay, 1990; Wannarka & Ruhl, 2008). Importantly, Wheldall and Lam (1987) provided evidence that these results also hold for students with difficulties in concentration and learning. Hence, arranging desks in rows rather than small groups is a valuable element of classroom management to promote students' concentration.

With respect to students' seat locations, teachers have generally been shown to prefer placing students with disruptive behaviors apart and sitting students with concentration, motivation, or learning difficulties near the teacher (Gremmen et al., 2016). As teachers further indicate that they primarily arrange seats for academic reasons, this element should constitute a relatively universal technique for fostering academic achievement among students experiencing impairment as a function of individual ADHD symptom levels (i.e., difficulties in concentration, motivation, and learning) as well as further learning problems. Hence, teachers' considerations when arranging seats accord with the common recommendation to allocate students experiencing academic impairment as a function of individual ADHD symptom levels to seat locations proximal to the teacher (e.g., DuPaul & Stoner, 2014; Mackowiak & Schramm, 2016; Merrell & Thymms, 2012; Pfiffner & Barkley, 1998) as well as the expectation that proximity to the teacher should decrease individual ADHD symptom levels and thus learning problems (Barkley, 1997; Draeger, Prior, & Sanson, 1986; Power, 1992). However, empirical evidence providing support for such recommendations is lacking, as prior studies demonstrating that students generally learn better when assigned seat locations proximal to the teacher, although this effect was not always statistically significant, did not take individual ADHD symptom levels into account (Bailenson et al., 2008; Meeks et al., 2013; Perkins & Wieman, 2004; Schwebel & Cherlin, 1972; Stires, 1980; Wulf, 1976). Consequently, this classroom management technique represents more of a gut instinct. In order to derive more evidence-based recommendations, the present study set out to investigate the effectiveness of seat locations proximal to the teacher for academic achievement.

1.3. The present study

The present study employed a virtual reality classroom in which participants were instructed on how to solve a math task they were previously unacquainted with. Additionally, they were taught a specific strategy that would help them solve a subset of problems faster (the taught solution strategy). Another strategy that would help them solve a different subset of items faster remained untaught (the untaught solution strategy). Hence, participants were expected to learn the taught solution strategy, but were not expected to learn the strategy they received no instruction on (as there was nothing they could have learned). Additionally, learning was assumed to be a function of individual ADHD symptom levels. Participants experienced the virtual math lesson in a seat location either proximal or distant to the teacher.

We aimed to investigate whether students' learning outcomes generally benefited from sitting proximally to the teacher. Moreover, we were interested in whether participants' individual levels of ADHD symptoms impaired learning. Finally, we aimed to examine whether the learning outcomes of students with higher individual levels of ADHD symptoms particularly benefited from sitting proximally to the teacher.

In particular, we hypothesized that a) students allocated to the proximal seat location would learn and thus apply the *taught solution strategy* better than those allocated to the distant one. However, b) no such difference was expected for the *untaught strategy*. Additionally, c) participants' individual levels of ADHD symptoms should be negatively associated with learning the *taught solution strategy*, but d) should not predict learning of the *untaught strategy*. Finally, e) we hypothesized that seat location would moderate the relation between the individual level of ADHD symptoms and learning the *taught strategy*, such that students with higher ADHD symptom levels should particularly benefit from sitting proximally to the teacher, but f) not for the *untaught strategy*.

2. Methods

2.1. Sample

Participants were recruited from local schools and invitations sent out on the university's mailing list. Recruitment in schools was approved by the Federal Ministry of Education and Cultural Affairs. The study was also approved by the local ethics committee.

Active written informed consent for study participation was

[2] This information relates to elements of classroom management aiming to compensate for student disadvantages. How to compensate for disadvantages experienced by students with symptoms of inattention or hyperactivity-impulsivity is usually up to the teacher's discretion and typically does not require a clinical diagnosis of ADHD to be implemented. Hence, students with low and clinically insignificant levels of ADHD symptomatology may profit from them as well.

obtained from both the participating children and their parents or legal guardians. All children and parents who indicated interest in participating in the study gave written informed consent and participated in the study. Children were eligible for participation if they did not report regular seizures or a prior diagnosis of epilepsy and were in fifth or sixth grade.[3] In accordance with prior research, all participants were assumed to experience ADHD symptoms to some degree (Levy et al., 1997; Lubke et al., 2009; Polderman et al., 2010). Their individual ADHD symptom level was assessed using a standardized questionnaire for ADHD symptoms filled in by one parent of each child (Conners 3, Lidzba, Christiansen, & Drechsler, 2013). The recruited sample comprised $N = 84$ children, but data from three participants had to be excluded due to missing values or misunderstood instructions. The final sample thus comprised $N = 81$ participants ($M_{age} = 11.27$ years, $SD_{age} = 0.68$; 35 female), of whom two had previously been diagnosed with ADHD and one with dyscalculia. $n = 34$ participants were in grade 5, whereas $n = 47$ participants were in grade 6. $n = 75$ participants were enrolled in the academic track and two in the intermediate track (no track information was available for four participants). All participants had normal or corrected-to-normal vision and indicated no hearing impairment. Mean ADHD symptoms in the recruited sample were $M = 0.76$ ($SD = 0.52$) on a four-point rating scale ranging from 0 (not at all/never/rarely) to 3 (in particular/very often). The recruited sample thus scored slightly higher than the normative sample for the Conners 3, $M_{normative\ sample} = 0.66$ ($SD = 0.47$), but substantially lower than the clinical sample, $M_{clinical\ sample} = 1.88$ ($SD = 0.47$; Lidzba et al., 2013). The fact that even the clinical sample scored only slightly above the mean of the scale should not be considered problematic, as the distribution of scale scores is right-skewed. Approximately half of the sample ($n = 39$) scored above the mean of the normative sample, $n = 9$ participants scored higher than one standard deviation, and $n = 3$ participants scored higher than two standard deviations above the mean of the normative sample. Hence, the recruited sample covers a wide range from low to high intensity of ADHD symptoms.

Table 1 presents further descriptive characteristics of the sample. Each participant was reimbursed for their participation with a voucher for a toy store (8 Euro). Parents were reimbursed with a voucher for a local café (4 Euro).

Table 1
Descriptive statistics [mean ± *SD* or *n* (%)] and ranges (observed range and [possible range]) for demographics and covariates in the sample (*n* = 81).

Variable		
Math grade	2.02 (0.91)	1.00–5.00 [1.00–6.00]
German grade (education in mother tongue)	2.28 (0.75)	1.00–5.00 [1.00–6.00]
Mother tongue		
German	71 (87.65)	
Other	1 (1.23)	
No information available	9 (11.11)	

2.2. Study design

Children participated in a virtual math lesson that took place in a virtual reality classroom (for a detailed description of the events in the classroom, see Appendix A). Virtual reality environments comprise synthetic, computer-generated, three-dimensional environments visualized to participants in real time (Adams, Finn, Moes, Flannery, & Rizzo, 2009; Kubo, Tori, & Kirner, 2002; Psotka, 1995). They enable the cost- and time-efficient testing of participants as well as optimal control of confounding variables (Adams et al., 2009). In the virtual classroom, participants were randomly allocated to a seat location either proximal or distant to the virtual teacher standing in front of the class. Randomization was stratified by gender and school grade.

During the math lesson, the virtual teacher introduced the number bisection task. The number bisection task is not part of the German math curriculum; the participants were thus expected to be unacquainted with it. The task required participants to indicate whether or not the central number in a number triplet reflects the arithmetic mean of the interval spanned by the two flanking numbers (e.g., 24_27_30 vs. 24_27_31, respectively; cf. Nuerk, Geppert, van Herten, & Willmes, 2002). Participants were first instructed that the number bisection task is generally solved by identifying whether the central number of the number triplet reflects the middle (i.e. arithmetic mean) of the interval. Moreover, as a specifically helpful strategy, they were told to first identify whether the outer numbers of a triplet differ in parity. If they do, this would allow them to immediately indicate that the central number is not the arithmetic mean of the triplet as the two outer numbers do not have an integer mean (e.g., 24_27_31, the actual mean would be 27.5; all numbers presented within the triplets were integers). After learning this strategy, participants were expected to respond faster to problems with flanking numbers different in parity than to those with flanking numbers of the same parity, which require calculating the arithmetic mean (e.g., 24_27_30 vs. 24_27_31, respectively). However, they were not expected to respond with a substantially lower overall error rate, as the time interval provided to respond (9 s) was considered long enough to determine the correct answer even when not applying the taught solution strategy, but rather calculating the arithmetic mean. Response times were therefore considered adequate to assess learning. An additional strategy that would likewise allow for faster verification of the arithmetic mean of some problems, but was not explained and hence not learned, would be to identify whether the numbers in a triplet come from a multiplication table (i.e., 12_18_24 vs. 11_17_23). After participating in the virtual math lesson, participants were assessed on the number bisection task to measure learning.

2.2.1. The virtual reality classroom

Fig. 1 provides an illustration of the virtual classroom design. The class comprised the participant, 25 fellow students, and one virtual teacher. Tables were arranged in a U-shaped fashion with additional tables inside the U. This arrangement of desks corresponded to the prevailing arrangement in German secondary schools. Fig. 2 presents the views from the proximal and distant seat locations within the virtual classroom. In the virtual classroom, distracting events (e.g., classroom door opens and closes again, paper plane flies by) and distracting behavior by fellow students (e.g., whispering, turning around) occurred randomly. In order to create a naturalistic representation of sitting in the back of the classroom, participants seated at a distance experienced the teacher's voice at a slightly lower volume compared to participants seated in front.

2.3. Procedure

Each participant attended one test session that took place in a quiet room either at the university or at their own school. No test session conflicted with teaching times. Only one participant was assessed at a time, and each test session lasted approximately 75 min, including preparation time. All data analyzed in the present study were collected in the first 35–40 min of the test session.[4] The experimenter welcomed

[3] The federal state in which the study was conducted, like the majority of German federal states, has a tripartite school system from fifth grade on with lower, intermediate, and academic tracks.

[4] The preparation phase in which the head-mounted display was adjusted to the participant's head and accelerometers were mounted to the non-dominant wrist, ankle, and hip lasted approximately 5 min. After attending the virtual math lesson and completing the number bisection task, the children

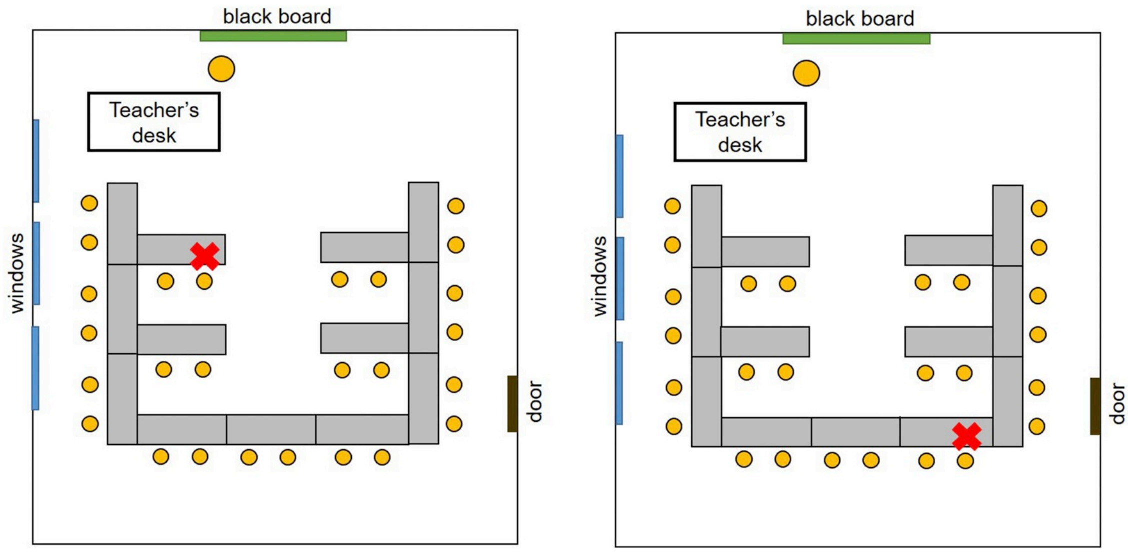

Fig. 1. Seat locations proximal and distant to the teacher (indicated by crosses).

Fig. 2. View of the virtual reality classroom from the proximal and the distant seat locations.

the child and accompanying parents upon arrival and answered any open questions. Next, the child was randomly assigned to either the distant or the proximal seat location in the virtual classroom he or she viewed through a head-mounted display (Oculus Rift). The participant then experienced a virtual math lesson in which the virtual teacher instructed him or her on how to generally solve the number bisection task. In addition, he or she was taught a specific strategy to solve a specific subset of problems faster. After the virtual math lesson, the participant left the virtual reality environment and completed the number bisection task. Prior to the test session, parents filled in an online questionnaire, which lasted approximately 30 min, at home.

2.4. Measures and questionnaires

2.4.1. Number bisection task

The number bisection task participants had to complete comprised 200 items presented on a standard laptop (screen width of 15.6 inches). Participants indicated their answers via button presses on a German standard QWERTZ keyboard. Pressing the left 'CTRL' key indicated that the central number was *not* the mean of the interval, whereas pressing the right 'CTRL' key indicated that the central number was the arithmetic mean of the triplet. The presentation time for each triplet and thus the time limit for participants' responses was 9000 ms. On average, participants responded after 4080 ms ($SD = 700$). When participants responded within the given time frame, the next item was presented after an inter-stimulus interval (ISI) of 1000 ms. When participants did not respond within the given time frame, their answer was coded as incorrect and the next item was presented. Each item was preceded by a fixation cross presented in the center of the screen during the second half of the ISI. Items were presented in four blocks of 50 items each with a break of 20 s between blocks. All items were presented in a randomized, non-stratified order. The split-half reliability of the number bisection task was 0.95 (Spearman-Brown corrected, calculated by correlating performance on items with even and uneven numbers after sorting them by bisection possibility and problem size, i.e., the arithmetic mean of the three numbers).

The number triplets were composed of numbers ranging between 10 and 99 in Arabic notation. A 2 × 2 within-participant design was applied including both bisectable (e.g., 24_27_30; requiring a 'yes' answer) and non-bisectable items (e.g., 24_27_31; requiring a 'no' answer). Multiplicativity (i.e., number triplets from a multiplication table vs. triplets not from a multiplication table, e.g., 12_18_24 vs. 11_17_23) and bisection range (i.e., numerical distance between outer numbers; large 12–18 vs. small 4–8, e.g., 16 in 4_12_20 vs. 4 in 10_12_14) were varied for bisectable items. For non-bisectable items, bisection possibility (i.e., whether the two outer numbers had an integer mean; e.g., 24_27_32 has a mean of 28 vs. 24_27_31 has a mean of 27.5) and distance between the central number and the correct arithmetic mean of the interval (large

(*footnote continued*)
additionally completed the Corsi Block Tapping Task (Corsi, 1972), the Stop Signal Task (Verbruggen, Logan, & Stevens, 2008), and a Digit Span Task (Petermann & Petermann, 2011). They also filled in a questionnaire on the instructional quality of the lesson. Data from the accelerometers, the Corsi Block Tapping Task, the Stop Signal Task, the Digit Span Task, and the questionnaire on instructional quality will be analyzed in future studies.

2–8 vs. small 0.5–1.5, e.g., 12_14_26, large with a distance of 5 vs. 12_20_26, small with a distance of 1) were manipulated. Problem size (mean of all numbers), average parity, parity homogeneity, decade crossings, and the inclusion of multiples of ten were matched across the stimulus groups.

The first *dependent variable,* which operationalized learning the strategy explicitly explained during the virtual math class, was calculated as the individual difference in mean response time (RT) to a) items requiring a 'no' response because they have no integer mean due to flanking numbers of differing parity (e.g., 24_27_31) compared to b) items requiring 'no' responses but have flanking numbers of the same parity (e.g., 24_27_32). This difference is termed the *bisection possibility effect*. This effect reflects the advantage of realizing that items with flanking numbers differing in parity do not have an integer mean. This advantage was expected to increase as a result of learning the strategy explicitly taught to participants. The second *dependent variable*, which operationalized applying an untaught and hence unlearned strategy during the virtual math lesson, was calculated as the individual difference in mean RTs to a) items requiring a 'yes' response because they come from a multiplication table (e.g., 12_24_36) compared to b) items requiring a 'yes' response, but are not from a multiplication table. This dependent variable is termed the *multiplicativity effect*, reflecting the advantage of realizing that the central number of items coming from a multiplication table always represents the correct arithmetic mean of the interval. As participants were not expected to learn this (untaught) solution strategy, no differences between participants were expected.

Data from the bisection task were first inspected for outliers on an individual level (i.e., RTs below 200 ms and RTs deviating from the individual mean by more than 3 *SD*). Response times identified as outliers were not considered in the analyses. Afterwards, data were again screened for extremely high overall error rates (the guessing rate was 50%), which might indicate that participants had not performed the number bisection task correctly. Two participants were excluded from further analyses.

2.4.2. ADHD symptoms

The participants' individual levels of ADHD symptoms were assessed using the long version of a German rating scale for ADHD symptoms comprising 110 items (Conners 3; Lidzba et al., 2013). All items were answered on a four-point rating scale ranging from 0 (not at all/never/rarely) to 3 (in particular/very often). The test-retest reliability of this questionnaire has been found to be $r = 0.85$ and its internal consistency was very good, with Cronbach's $a = 0.91$ (Lidzba et al., 2013). The questionnaire was filled in by one parent of each child included in the study. The independent variable calculated from the Conners 3 was the general index, defined as the mean value of the ten items of the questionnaire assumed to best detect ADHD symptoms, and which commonly serves as a screening instrument (Lidzba et al., 2013).

2.5. Analyses

In order to compare learning in the proximal versus distant seat location (both effect coded) and to evaluate whether ADHD symptoms predicted learning the taught and untaught solution strategies, multiple linear regression analyses with seat location and ADHD symptoms as the independent variables and the bisection possibility and multiplicativity effects as dependent variables were conducted. Finally, moderation analyses were calculated to test whether seat location moderated the relation between ADHD symptoms and learning. In all analyses, the dependent variables were adjusted for school grade and gender using standard regression procedures. German and math grades were not controlled for as they were associated with individual ADHD symptom levels and as substantial research suggests that ADHD symptoms predict poorer academic achievement (Biederman et al., 1996; DuPaul et al., 2004; Klein, Mannuzza, Olazagasti, & Al, 2012; Mannuzza et al., 1993; Mannuzza, Klein, Bessler, Malloy, & Hynes, 1997; McGee, Partridge, Williams, & Silva, 1991).

The directions of all hypotheses with the *taught solution strategy* (i.e., bisection possibility effect) as the dependent variable are backed by strong theoretical and empirical evidence. First, substantial research corroborates the expectation that students should learn better when seated proximally to the teacher (i.e., Hypothesis a; Bailenson et al., 2008; Meeks et al., 2013; Perkins & Wieman, 2004; Schwebel & Cherlin, 1972; Stires, 1980; Wulf, 1976). Additionally, individual levels of ADHD symptoms have been consistently observed to impair learning (i.e., Hypothesis c; Barry et al., 2002; Biederman et al., 1996; DuPaul & Stoner, 2014; Loe & Feldman, 2007; Merrell & Tymms, 2001; Polderman et al., 2010). Finally, as for Hypothesis e, teachers have been found to generally prefer seating students with higher levels of ADHD symptoms more proximally to the teacher (Gremmen et al., 2016). This also coincides with common recommendations and assumptions that this decreases ADHD symptoms and thus fosters children's academic achievement (Barkley, 1997; Draeger et al., 1986; DuPaul & Stoner, 2014; Mackowiak & Schramm, 2016; Merrell & Thymms, 2012; Pfiffner & Barkley, 1998; Power, 1992). Hence, these directional hypotheses with the taught solution strategy as the dependent variable were tested one-tailed, in line with recommendations (cf. Fisher & Yates, 1943; Westermann & Hager, 1986).

However, as students did not receive explicit instruction on the *untaught solution strategy* (i.e., multiplicativity effect), they were not expected to learn and hence apply this strategy. As such, no difference in learning the untaught solution strategy was expected between proximal and distant seat locations (Hypothesis b). Additionally, individual levels of ADHD symptoms were not expected to influence learning, as students were not expected to learn the strategy (Hypothesis d). Therefore, we did not expect seat location to moderate the relation between individual ADHD symptom levels and learning the untaught solution strategy (Hypothesis f). Because we had no directed hypotheses on the untaught solution strategy, these non-directional hypotheses were tested two-tailed (cf. Fisher & Yates, 1943; Westermann & Hager, 1986).

All analyses were run with the dependent variables calculated on the basis of z-standardized RTs to control for inter-individual differences in overall RT. Individual mean RTs and standard deviations were used for standardization. As such, the statistical details reported in the results section refer to analyses of z-RTs. However, for easier interpretation, we also present results in plain RT.

3. Results

Table 2 presents the descriptive characteristics of the two subsamples after randomization to either the proximal or the distant seat location. Importantly, the groups did not differ significantly on any of the presented variables. Differences in degrees of freedom are attributable to missing data.

Table 3 presents the correlations of the dependent variables bisection possibility effect and multiplicativity effect with covariates.

3.1. Do students in general learn better in proximal seat locations?

As can be seen in Table 4, seat location significantly predicted learning of the bisection possibility effect (i.e., taught solution strategy). The group sitting proximally to the teacher in the virtual reality classroom learned significantly better than the group sitting further away, indicating that the group in close proximity to the teacher benefited more from being taught the strategy ($M_{proximal} = 338$ ms ($SD = 358$), $M_{distant} = 198$ ms ($SD = 325$); see Fig. 3). Note that these results tested our directional hypothesis, derived from consistent empirical evidence (e.g., Bailenson et al., 2008; Meeks et al., 2013; Perkins & Wieman, 2004), that students would learn better when sitting proximally to the teacher and were thus tested one-tailed. In contrast, seat location did not significantly predict learning of the

Table 2
Descriptive statistics [mean ± *SD* or *n* (%)] and ranges for demographic variables and covariates after randomization to proximal and distant seat locations.

Variable	Proximal (n = 38)	Empirical range [Possible range]	Distant (n = 41)	Empirical range [Possible range]	Statistics
ADHD Symptoms	0.75 (0.42)	0.10–1.80 [0.00–3.00]	0.72 (0.54)	0.00–1.90 [0.00–3.00]	t (73) = 0.37, p = .72
Age	11.17 (0.66)	10.00–12.33	11.39 (0.71)	10.25–12.83	t (70) = −0.67, p = .19
Math grade	1.91 (0.79)	1.00–4.00 [1.00–6.00]	2.05 (0.95)	1.00–5.00 [1.00–6.00]	t (72) = 0.32, p = .51
German grade	2.30 (0.79)	1.00–4.00 [1.00–6.00]	2.24 (0.72)	1.00–4.00 [1.00–6.00]	t (72) = −1.34, p = .75
Gender					
male	21 (55.26)		24 (58.54)		χ^2 (1) = .086, p = .77
female	17 (44.74)		17 (41.46)		
Grade					
5	16 (42.11)		17 (41.46)		χ^2 (1) = .003, p = .95
6	22 (57.89)		24 (58.54)		
Mother tongue					
German	35 (92.10)		34 (82.92)		p > .99
Other	1 (2.63)		0 (0.00)		
N/A	2 (5.26)		7 (17.07)		
ADHD diagnosis					
No	36 (94.74)		37 (90.24)		p > .99
Yes	1 (2.63)		1 (2.44)		
N/A	1 (2.63)		3 (7.32)		
Dyscalculia					
No	36 (94.74)		38 (92.68)		p = .49
Yes	1 (2.63)		0 (0.00)		
N/A	1 (2.63)		3 (7.32)		
School track					
academic	37 (97.37)		37 (90.24)		p > .99
intermediate	1 (2.63)		1 (2.44)		
N/A	0 (0.00)		3 (7.32)		

Note: An independent samples *t*-test (two-tailed) was calculated to compare the mean values of the groups randomized to the proximal and distant seat locations. Chi-square tests or Fisher's exact tests (two-tailed) were calculated to compare the distribution of the categorical descriptive variables.

Table 3
Correlations of the bisection possibility effect and the multiplicativity effect (dependent variables) with covariates for the samples sitting proximally (upper triangle) and distant (lower triangle) to the teacher, respectively.

Variable	1	2	3	4	5	6	7	8
1. Bisection possibility effect		.01	−.11	.25	−.02	.29°	.00	.16
2. Multiplicativity effect	.22		.23	.17	−.09	.17	.12	.11
3. ADHD symptoms	−.31°	.11		.02	−.43*	.08	.51*	.50*
4. Age	−.25	−.01	.02		−.08	.78*	.34°	.15
5. Gender	.01	−.20	−.28°	.16		.02	−.20	.34*
6. School Grade	−.07	.05	−.02	.70*	.01		.20	.11
7. Math grade	−.24	−.08	.13	.33°	.21	.25		.65*
8. German grade	−.21	.22	.48*	.08	−.16	.03	.63*	

Note: Pearson's correlations tested two-tailed, °p < .10, *p < .05; gender coded as 0 (male) and 1 (female).

Table 4
Summary of the regression analysis for seat location and ADHD symptoms predicting learning of the taught and untaught solution strategies.

Variables	Taught solution strategy					Untaught solution strategy				
	B	SE	β	t	p	B	SE	β	t	p
Constant	.077	.043		1.79	.078	−.031	.037		−.84	.41
Seat location	−.045	.024	−.22	−1.93	.029*[a]	.010	.020	.058	.50	.62
ADHD symptoms	−.098	.050	−.22	−1.98	.026*[a]	.043	.042	.12	1.02	.31

Note: seat locations effect coded (proximal: -1; distant: 1); dependent variable *taught solution strategy*: R^2 = 0.092, F(2,74) = 3.65, p = .031; dependent variable *untaught solution strategy*: R^2 = 0.017, F(2,74) = 0.62, p = .54; *p < .05; [a]tested one-tailed.

multiplicativity effect (i.e., untaught solution strategy; $M_{proximal}$ = 7 ms (SD = 244), $M_{distant}$ = 27 ms (SD = 326)). As students were not expected to learn the untaught solution strategy, directional assumptions were lacking and were tested two-tailed.

3.2. Do ADHD symptoms predict learning?

As presented in Table 4, ADHD symptoms significantly negatively predicted learning of the bisection possibility effect (i.e., taught solution strategy). Hence, children with higher levels of ADHD symptoms

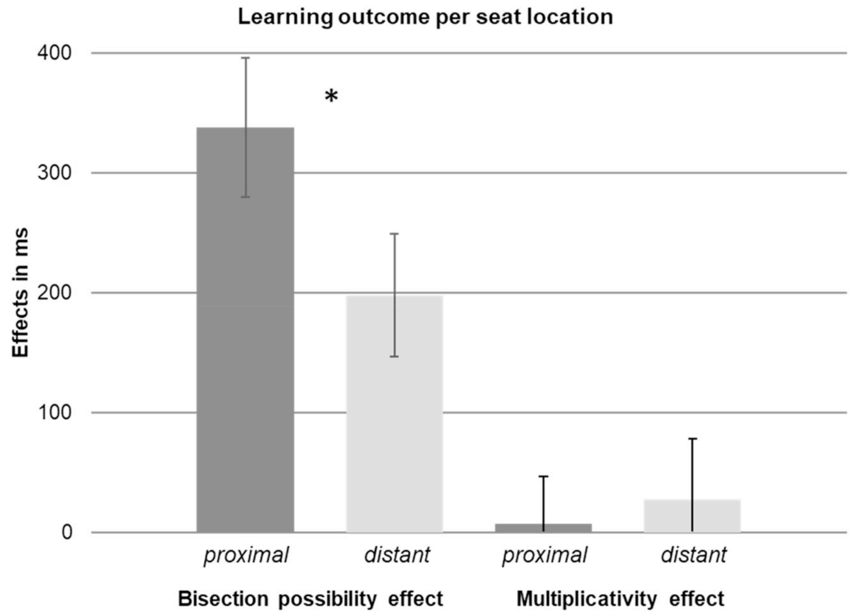

Fig. 3. Mean bisection possibility effect and mean multiplicativity effect in milliseconds based on plain RTs for proximal and distant seat location (error bars indicate standard errors).

Table 5
Summary of the moderation analysis for seat location moderating the relation between ADHD symptoms and learning the taught solution strategy.

Variables	*B*	*SE*	*t*	*p*
Constant	.005	.024	.19	.86
ADHD symptoms	−.093	.052	−1.80	.039*[a]
seat location	−.045	.024	−1.91	.031*[a]
seat location x ADHD symptoms	−.022	.052	−.42	.34[a]

Note: seat locations effect coded (proximal: −1; distant: 1); R^2 = 0.094, $F(3,71) = 2.46$, $p = .069$; *$p < .05$; [a]tested one-tailed.

profited less from being taught the strategy. Note that these results again tested our directional hypothesis that individual levels of ADHD symptoms would impair learning (e.g., Merrell & Tymms, 2001; Polderman et al., 2010) and were thus tested one-tailed.

However, ADHD symptoms did not predict the application of the untaught solution strategy (i.e., the multiplicativity effect). As students were not expected to learn the untaught solution strategy, ADHD symptoms were not expected to impair its acquisition, which constitutes a non-directional assumption. Accordingly, the results of the regression analysis with the untaught solution strategy as the dependent variable were tested two-tailed.

3.3. *Does seat location moderate the relation between ADHD symptoms and learning?*

The moderation analysis performed in order to test whether seat location moderated the relation between ADHD symptoms and learning the taught solution strategy indicated no significant moderation. Only from a descriptive perspective did students in the distant seat location experience a stronger decrease in learning with increasing ADHD symptoms compared to students in the proximal seat location. Estimates from the regression analysis are presented in Table 5. Please note that these results again tested our directional hypothesis that students with increasing ADHD symptom levels should particularly benefit from sitting proximally to the teacher and were therefore tested one-tailed (e.g., Greene et al., 1996; Gremmen et al., 2016; Merrell & Thymms, 2012; Merrell & Tymms, 2001; Pfiffner & Barkley, 1998; Power, 1992).

Table 6
Summary of the moderation analysis for seat location moderating the relation between ADHD symptoms and learning the untaught solution strategy.

Variables	*B*	*SE*	*t*	*p*
Constant	.000	.020	.022	.98
ADHD symptoms	.046	.044	1.05	.29
seat location	.010	.020	0.49	.62
seat location x ADHD symptoms	−.012	.044	−.27	.79

Note: seat locations effect coded (proximal: −1; distant: 1); R^2 = 0.018, $F(3,71) = 0.43$, $p = .73$.

A test of whether seat location moderated the relationship between ADHD symptoms and the multiplicativity effect (i.e., the untaught solution strategy) revealed no significant results. Estimates from the regression analysis are presented in Table 6. Two-tailed statistical significance tests were applied as ADHD symptoms were not expected to impair learning of the untaught solution strategy and seat location was therefore not expected to moderate this relation (i.e., a non-directional assumption).

4. Discussion

The present study sought to investigate whether students generally benefited from sitting proximally to the teacher with respect to numerical learning in a virtual math lesson. Moreover, we aimed to examine whether participants' individual levels of ADHD symptoms impaired learning. Finally, we aimed to investigate whether students learned better when sitting proximally to the teacher as a function of their individual ADHD symptom levels. a) Our results supported the expectation that students seated proximally to the teacher learn the taught solution strategy better than those seated further away. b) This effect was specific, as it was not observed for the untaught solution strategy. Our results furthermore supported c) the hypothesis that ADHD symptoms negatively predict learning, as ADHD symptoms were associated with impaired learning of the explicitly taught strategy. d) This assumption was further supported by the lack of association between ADHD symptoms and the untaught solution strategy. e) The results of the present study did not support the hypothesis that a proximal seat location fosters student learning differentially depending on a student's individual ADHD symptom level. From a descriptive point of view, our results suggest a stronger decline in learning among children seated far away from the teacher as ADHD symptoms increase. f) The results supported for the assumption that seat location did not moderate the relation between ADHD symptoms and the application of the untaught solution strategy.

Our findings supported the assumption that sitting proximally to the teacher during an instruction phase fosters learning in comparison to sitting further away. Thus, our results are in line with prior studies assessing adults' learning and academic performance (Bailenson et al., 2008; Meeks et al., 2013; Perkins & Wieman, 2004; Schwebel & Cherlin, 1972; Stires, 1980; Wulf, 1976). Moreover, our results supported the assumption that individual levels of ADHD symptoms impair student learning. Thus, our results from a virtual math lesson are in accordance with prior research conducted in real-life classrooms (DuPaul & Stoner, 2014; Lubke et al., 2009; Polderman et al., 2010). Extending prior research, our findings did not support the assumption that sitting proximally to the teacher differentially fosters learning as a function of individual ADHD symptom levels. However, from a descriptive perspective, our results suggest that children may experience larger decreases in learning in a distant seat location with increasing ADHD symptoms.

4.1. Practical and methodological implications

The present findings have several practical implications. First, our results showing that students generally learned better in proximal seat locations imply that ideally all students should sit in the front. However, as classrooms offer only a few seats close to the teacher, teachers might wish to distribute their presence evenly throughout the classroom or rotate students' seat locations regularly. This would allow all students to benefit equally from the positive effects of teacher proximity for academic achievement. Future studies might wish to determine whether distributing teachers' classroom presence evenly or rotating seat locations fosters academic achievement among all students in a class.

Additionally, as our data indicated no differences in learning as a function of individual ADHD symptom levels between proximal and distant seat locations, taking students' ADHD symptoms into account when arranging seats might be considered irrelevant (cf. Gremmen et al., 2016). However, our results also suggested a trend in the direction of increasing impairment in the distant seat location with increasing ADHD symptoms. Consequently, teachers might still wish to take students' ADHD symptoms into consideration when arranging seats. Nevertheless, the effects of proximal seat locations in relation to students' individual ADHD symptom levels seem to be smaller than generally expected.

The present study's findings that student learning is generally better in proximal compared to distant seat locations further imply that online teaching and tutoring programs using virtual reality technology might wish to allocate all students to seats proximal to the virtual teacher. Such programs can be used to support learning in real-life classrooms or replace real-life classrooms when children cannot visit school regularly due to living in remote locations or being in hospital, for instance. Given that this is technically possible, we argue that it should be implemented in order to optimally foster all students' academic performance.

In addition to these practical implications, the present results have important methodological implications for future research. First, our results provide support for the feasibility and validity of conducting studies using virtual reality classrooms, as the present study successfully replicated results from prior studies conducted in real-life classrooms. Specifically, we obtained evidence of a negative association between learning and students' individual levels of ADHD symptoms (DuPaul & Stoner, 2014; Merrell & Tymms, 2001; Polderman et al., 2010) and for poorer learning among students allocated to distant rather than proximal seats (Bailenson et al., 2008; Meeks et al., 2013; Perkins & Wieman, 2004; Schwebel & Cherlin, 1972; Stires, 1980; Wulf, 1976). As virtual reality environments allow for time- and cost-efficient testing as well as highly standardized experimental and test settings, we consider them a promising tool for future studies in educational research.

Additionally, the present study's findings further support the notion that ADHD represents a continuum spanning from very low to very intense symptomatology (e.g., Coghill & Sonuga-Barke, 2012). Our findings from a sample of children largely scoring below clinically meaningful ADHD symptom levels equaled those of prior studies showing that academic achievement is impaired in children with diagnosed ADHD (Barkley, 2006; DuPaul & Stoner, 2014; Loe & Feldman, 2007). Consequently, we suggest that recruiting children with clinical ADHD diagnoses is not necessary in research aiming to uncover effects that should also occur in individuals scoring below clinically meaningful ADHD symptom levels. The present findings indicate that these effects should also be observable in an ordinary population sample.

4.2. Limitations and implications for further research

To the best of our knowledge, the present study was the first to take students' individual levels of ADHD symptoms into account when assessing the relation between seat location and academic achievement in a virtual classroom. Future studies aiming to replicate and extend its findings should consider the following limitations of the present study. First, the present study may have generally underestimated learning results as learning was assessed outside the virtual classroom in a laboratory setting. Completing the assessment in an environment other than the one in which learning occurred required participants to transfer their newly acquired knowledge. However, several studies indicate that the recall of learned material is context-dependent and thus hampered when transfer is required (Gershman, 2017; Godden & Baddeley, 1975; Grant et al., 1998). Consequently, in order to prevent potential underestimations of learning results, future studies should conduct testing in the same virtual classroom environment in which learning occurred (e.g., by visualizing a keyboard and computer screen so that the participant can solve the number bisection task within the virtual classroom or by using eye movements to indicate answers).

In addition, future studies should further develop virtual classrooms in order to increase their authenticity. For instance, the classroom in the present study did not translate a participant's body movements onto his or her virtual body in the virtual environment. Moreover, participants could not engage in teacher-pupil discussions or interact with their virtual fellow classmates or the teacher. This may have negatively influenced the participants' feeling of presence (i.e., the feeling of being within the virtual world; Psotka, 1995), which is considered important for eliciting naturalistic behaviors in virtual environments (Bohil, Alicea, & Biocca, 2011). In order to foster participants' feeling of presence and thus better approximate the real-life quality and quantity of elicited behaviors, future studies should aim to improve virtual classrooms from an immersion perspective (i.e., the degree of physical stimulation of the sensory systems and the sensitivity of the systems to these inputs; Psotka, 1995). This would further improve the generalizability of results from studies using virtual classrooms to real life.

A further limitation of the present study was that the sample almost entirely comprised students from the academic secondary school track. Due to more strongly impaired academic performance among students with increased levels of ADHD symptomatology (Barry et al., 2002; Polderman et al., 2010), such students are assumed to be more often allocated to lower tracks. Samples recruited from lower track or primary schools should therefore include a higher proportion of students with more pronounced or even intense ADHD symptoms. Consequently, future studies should examine whether the results obtained in the present study can also be generalized to samples including more children with intense ADHD symptomatology, potentially from school tracks other than the academic one.

Additionally, the results of the present study using a U-shaped arrangement of desks do not necessarily generalize to other types of arrangements (i.e., rows or small groups), as it is still unclear whether and how seat location and desk arrangement differentially interact. Hence, future studies should evaluate whether seat locations proximal to the teacher improve students' behavior and academic achievement in classrooms using a non-U-shaped arrangement of desks, both when individual levels of ADHD symptoms are taken into account and when they are not.

Moreover, future studies should consider the influence seat location and proximity or distance to certain fellow virtual classmates have on participants' feeling of likeability and popularity. Studies conducted in real-life classrooms suggested that children sitting closer to the center of the classroom are liked more than those sitting at the boundaries (e.g., van den Berg & Cillessen, 2015; van den Berg, Segers, & Cillessen, 2012). These and other prosocial factors are associated with students' academic achievement (e.g., Wentzel & Kathryn, 2006). Hence, future studies may wish to take such factors into consideration when interpreting their results.

Finally, future studies may wish to additionally assess symptoms of hyperactivity, impulsivity, and inattention in the virtual classroom using psychophysiological measures. Such an approach would allow individual levels of ADHD symptoms to be captured in a state-like approach, acknowledging that ADHD symptoms are context-dependent and thus assessing them in an ecologically valid setting. Questionnaires such as those used in the present study assess ADHD symptoms as a trait, thereby ignoring the state-like component and the context (Imeraj et al., 2013; Schmid, Stadler, Dirk, Fiege, & Gawrilow, 2016). Assessing individual levels of ADHD symptoms in this way could increase the validity and generalizability of findings.

5. Conclusion

The present study was the first to take students' individual levels of ADHD symptoms into account when assessing the relation between seat location and academic achievement. One substantial strength of the present study was its use of a virtual reality classroom, thus guaranteeing a highly standardized experimental setting controlling for the influence of confounding variables. The results of the present study supported the assumption that all students benefit from sitting proximally to the teacher with respect to learning results. However, students with higher individual levels of ADHD symptoms did not specifically benefit from a proximal seat location. Consequently, the present investigation did not support the common assumption that seat locations proximal to the teacher specifically foster academic achievement in students experiencing increased levels of ADHD symptoms.

Declaration of conflicting interests

None.

Funding

This research was funded by the Intramural Research Fund of the LEAD Graduate School & Research Network [GSC1028], a project of the Excellence Initiative of the German federal and state governments. Additionally, the research reported here is based on work supported by the Postdoc Academy of the Hector Research Institute of Education Sciences and Psychology, funded by the Baden-Württemberg Ministry of Education and Cultural Affairs.

Acknowledgements

We thank all children and parents for their participation. In addition, we thank all participating schools for their assistance in recruiting participants. We also thank Julian-Till Krimly, Katharina Kühn, and Nana Ambs for their help with collecting data, and Angelika Schmitt, Anne Eppinger-Ruiz de Zarate, and Tobias Deribo for their help with entering and preparing the data.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.learninstruc.2018.10.004.

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