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ArticleTitle	Computer-generated geometry instruction: a preliminary study	
Article Sub-Title		
Article CopyRight	Association for Educational Communications and Technology (This will be the copyright line in the final PDF)	
Journal Name	Educational Technology Research and Development	
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Schedule	Received	
	Revised	
	Accepted	
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Keywords (separated by '-')	Computer-generated instruction - Attention disorders - Mathematics - Attention - Learning	
Footnote Information		

Education Tech Research Dev
DOI 10.1007/s11423-011-9186-5

RESEARCH ARTICLE

Computer-generated geometry instruction: a preliminary study

Helen W. Kang · Sydney S. Zentall

Abstract This study hypothesized that increased intensity of graphic information, presented in computer-generated instruction, could be differentially beneficial for students with hyperactivity and inattention by improving their ability to sustain attention and hold information in-mind. To this purpose, 18 2nd–4th grade student, recruited from general education classes, were presented with sequenced geometry instruction, which involved projections of solid geometric images accompanied by text and color. Children were randomly assigned to two levels of intensity: high visual intensity (HVI) with information from the light source (e.g., contrasts, shadows) and low intensity (LVI) projecting only a single value. In support of theoretical predictions, students with hyperactivity/inattention performed better than typical comparisons during the performance of advanced problems in the HVI condition. Furthermore, the students with inattention demonstrated significantly better performance in the HVI than in the LVI condition. Educational, research, and development implications of these findings were discussed.

Keywords Computer-generated instruction · Attention disorders · Mathematics · Attention · Learning

Educators want efficient ways to prepare students for new roles in a complex society, but have voiced concern about how to integrate students with diverse characteristics into an inclusive curriculum. Lesh proposes that learners in the 21st century will need to know how to (a) describe relationships among quantities, using text, tables, and graphs, (b) explain why something that appears to be true is not, and (c) justify and predict why one procedure has advantages over others (Lesh 1994, 1998; Lesh and Doerr 1998). That is, the content of mathematics must become more communicative/persuasive in nature, and the delivery of instruction must be more technologically advanced to address the diverse characteristics of student populations.

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Traditional education and most accumulated research on mathematics has focused on mastery of a fixed body of information (Kay et al. 1994). This focus on facts rather than applications could explain outcomes that underachievement in mathematics increases as children age (Jordon and Hanich 2003; Nussbaum et al. 1990). When math instruction focuses on memorizing facts rather than understanding concepts and applying information, it could also place children with learning disabilities (LD) at an even greater disadvantage because of their well-documented problems in attention and memory.

Students with attention deficit hyperactivity disorder (ADHD) are also placed at a greater disadvantage in mathematics, because of the critical role that attention plays in math performance (Zentall 2007). In addition to their difficulties sustaining attention to repeated practice required for memorizing facts, attention to the deep structure in math problems is necessary for concept development. For example, it has been reported that individuals who actively attend at a deeper level into the structure or elements of math problems have better conceptual knowledge and procedural skill to apply to novel problems and better performance on assessments of generality (Hiebert and Wearne 1986; Jonassen 2003; Kercood et al. 2004).

There are specific attentional skills that encourage such an in-depth analysis. One that is currently receiving considerable attention is working memory. Working memory involves the ability to hold information in mind while engaging in other mental processing (e.g., to update, reorganize, or apply information) (Geary et al. 2007). There are two types of working memory (auditory and visual). Auditory working memory contributes to the use of mature problem-solving strategies and procedures, especially during initial learning trials (Geary et al. 2007; Swanson 2007). Mathematical difficulties attributable to poor auditory working memory that have been documented for children with attention disabilities (at-risk for ADHD) are related to holding and manipulating mathematical steps or procedures, changing the order of information, and performing mental mathematics and multiple actions or operations (Zentall 2007). As well, difficulty holding visual spatial information in mind has been found in association with low achievement in mathematics (Gathercole and Pickering 2000) and could contribute to specific math problems (e.g., reversing figures, visualizing hidden lines, estimating, using visual symbols, and application of visual concepts (numerosity, place value, time, distance, age).

For children with clinically-diagnosed ADHD and for those at-risk for ADHD in general educational settings, working memory may act alone to compromise performance in math in spite of average IQ. The failure of children with ADHD to maintain representations of information in-mind (working memory) (McInnes et al. 2003) can be attributed to *their* core deficits in sustained attention. In fact, the interrelationship between sustaining attention and holding information in mind is so tightly woven that some researchers state that 'working attention' may be a better term than working memory (i.e., memory involves storing information) (Kaplan et al. 2000; Sergeant et al. 2003).

It may be more difficult for children with ADHD to sustain attention, because they habituate to stimuli more rapidly than typical peers (e.g., Sergeant et al. 2003), causing task information to lose impact over time. When optimal stimulation is *not* available for these students from their tasks, they reallocate their attention internally or externally to that which is bigger, brighter, louder, moving, colorful, or emotional (Copeland and Wisniewski 1981; Radosh and Gittelman 1981; Zentall 1986). In the process of seeking stimulation through attention to change or novelty, it would be difficult for these students to hold previous task information in mind. Such difficulties could explain evidence that these children have math disabilities at four times the rate of typical students (Mayes et al. 2000; Shalev et al. 2001).

If there were technological adaptations that could increase the salience of task stimulation (e.g., color, animation, emotion, interest) and thereby increase arousal, especially towards the end of performance when habituation occurs, it could help these students sustain attention (for review of the optimal stimulation theory see Zentall and Zentall 1983; Zental 2005). One well-known intervention that is effective in improving the ability of students with ADHD to sustain attention is psycho stimulant medication (Bedard et al. 2004). However, compliance rates and side effects detract from this intervention (for review see Zentall 2006). Alternative methods could involve adding intense stimulation or novelty to relevant features of tasks with graphic representations (i.e., requiring less auditory working memory or verbal cognitive processing, Larkin and Simon 1987).

Graphics could enrich students' mental representations and increase their ability to generate and hold images in mind (Kosslyn 1988). Graphics may be particularly important in learning new concepts (Bertoline 1998; Purnell et al. 1991) and can be manipulated through technology to improve sustained attention (e.g., Lewis 1993). Prior research with this population has documented improvements in simple tasks (e.g., handwriting, spelling performance) with added color (for review see Zentall 2005), but no research has examined other types of visual stimulation. To this purpose, the current study used instructional software to present geometry problems.

Specific predictions were that students with inattention and hyperactivity/inattention should perform better than a comparison group of peers with graphical information presented with salient input from the light source (gradient, contrasts, transparency, illuminations, shadows and/or highlights) than a control group with geometric figures presented with the same color but with only a single value and no input from the light source.

Overall, the potential contribution of this study is related to the use of instructional software to present higher level mathematics (geometry applications) in combination with a theoretically-based intervention (added stimulus input from a light source) for a group of students at-risk for ADHD, who represent 8–20% of community samples worldwide and 3 to 7% of children with a clinical-diagnosis of ADHD (Faraone et al. 2003; Shaywitz and Shaywitz 1988).

Method

Participants

The participants in this study were 18 2nd–4th grade students from local public schools. For research purposes 12 of these students were classified as inattentive or inattentive and hyperactive using criterion scoring (*T*-score of 60 or greater) on teacher ratings (the Conner's Teacher Rating Scale-Revised, CTRS-R: S, Conners 1997). Using this criterion, 3 students were 1 *SD* above the *M*; 5 students were 2 *SD* above; 4 students were 3 *SD* above–an expected range in severity from mild to severe in general education.

The CTRS-R: S, which was used for grouping, consists of 28 items constructed to reflect characteristics used in the diagnosis of ADHD, and allows for subtyping: the hyperactive-impulsive subtype (ADHD-H), the inattentive subtype (ADHD-I), and the combined subtype (ADHD-C), as stated in the *Diagnostic and Statistical Manual of Mental Disorders* fourth edition (*DSM-IV-TR*) (American Psychiatric Association 2000). The CTRS-R: S demonstrates good internal and test–retest reliabilities (.88 to .95 and .72 to .92, respectively, Conners 1997). There is recent evidence that teacher ratings (e.g., including an earlier version of the Conners) were moderately to strongly related to student behavior recorded by an independent observer over 3 to 4 days (off-task: $r > .41$; on-task: $r > -.70$, Lauth et al. 2006). More generally additional validity has been shown rating scales for ADHD that have specificity greater than 94% in studies differentiating children with ADHD from normal, age-matched, community comparisons (AAP 2001).

We subdivided this sample into four students (3 males; 1 female) representing the inattentive subtype (ADHD-I), defined by criterion scoring at least 1 SD above the mean on the "inattention index," and eight students (7 males; 1 female) who met the criteria for combined subtype (ADHD-C), with criterion scoring on both the inattentive and the hyperactivity index. These two subtypes represent over three quarters of the overall ADHD population (Wilens et al. 2002); the inattention that characterizes both subtypes indicates that both subtypes are more likely to have co-occurring academic problems (Wilcut and Pennington 2000).

Because we were not able to (a) assess age of onset of ADHD, (b) require parental ratings, in addition to teacher ratings, nor (c) conduct diagnostic interviews, the current study labeled this school-based sample as being at-risk for a clinical diagnosis of ADHD. That is, ADHD "occurs along a continuum," and studies employing children with a clinical diagnosis of ADHD typically represent only the extremes of this continuum (Epstein et al. 1991, p. 85), with concerns about the selectivity of clinic referrals (i.e., children with co-occurring conditions).

Unfortunately, district wide consent was *not* granted for access to student records. This precluded our ability to report descriptive data; thus, our students may have had co-occurring disabilities (e.g., Oppositional Defiant Disorder, Conduct Disorder) and may have been taking psychostimulant medication at the time of the study, although their general education placement and teacher ratings would indicate otherwise.

These students were compared with 6 typical comparison students (5 males; 1 female), who had been randomly selected from within the same classes and who had *T*-scores of 50 or lower, indicating the relative absence of attentional or activity problems. Statistical differences among these three groups in chronological age were not found, $F(2, 16) < .5$.

We selected more students who were at-risk for disabilities in this study to offset variability that is more often documented in the behavior and performance of these students than in comparison samples. Unequal sample sizes are acceptable if the ratio of the largest to the smallest sample size is less than 4 to 1 (Tabachnick and Fidell 1996).

Experimental setting and procedure

The experimental areas varied somewhat in each school but were on average 3.5 m × 3.0 m with 2–3 blinded windows. The experimenter and second observer, who was present the majority of the time to establish reliability, sat behind the participant, who was seated at the long end of a conference table (1.1 m × 2.3 m).

Common to both conditions was the use of a laptop computer, instructions and procedure, a 15 min paper and pencil pretest, a 20 min computer administered geometry instructional task, and a 15 min paper and pencil posttest (described below).

Pre- and post-tests

The content of new materials to be learned for the pre and posttests was based on a statewide textbook prescribed for 4th grade classrooms (Hake and Saxon 2004). The students could already identify shapes, such as, triangle, square, and circle, however, they needed instruction on the properties of these geometric shapes (equilateral triangles

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have three sides; isosceles have two sides that are equal) and how to calculate the perimeter of these shapes. That is, calculating the perimeter of 2D flat shapes would be presented later within the 7th grade curriculum and assessed even later in the 8th grade statewide assessment. Thus, the intervention would present information not previously presented or assessed for these 2nd through 4th graders."

A pencil-and-paper format was used initially to reduce variation created by possible differences in users' previous experiences with technology (Rouet 1993). The two test forms were constructed to be equivalent–each with 14 items (12 fill-ins, 1 true/false, 1 multiple choice). The content of the items on the equivalent forms required students to: (1) draw specific triangles with given characteristics (2 questions), (2) identify (or match with the list of terminologies) the definition and/or characteristics of shapes and solid figures (5 questions), (3) determine whether the given statement was true or false (1 question), (4) perform multi-step addition (1 question), (5) calculate the perimeter of 2-D planar images from given length and width dimensions (2 questions), (6) identify and name different shapes based on the images that were provided (right and equilateral triangles, rectangle, square, rhombus, and trapezoid) (2 questions), and (7) find the perimeter of a cube given its image and length of one of the sides (1 question).

Instructions and task

In a written introduction, a text message appeared on a computer monitor that said, "Welcome! Today we are going to learn about geometry. As we progress, we will learn more about different geometry shapes and calculate the perimeter of these shapes. Let's begin!" The instruction was *self-paced*, with content[1] that was similarly based on Saxon's textbook (Hake and Saxon 2004). Participants navigated each instructional screen by clicking either the 'Previous' or the 'Next' button with a mouse. In other words, there were pauses between items and the students could proceed at their own pace to the next shape or go back to reexamine the previous image(s). A total of 17 screens of simplified instruction followed (averaging 5 lines of text per screen) and consisted of geometric shapes, terminology, and calculations of the perimeter of solid geometric-figures (i.e., rectangles, triangles, circles, prisms, cubes, cones, cylinders, pyramids, and spheres).

Participants first read the text information on the screen (e.g., "A triangle is one of the basic shapes of geometry. A triangle has three sides.") This screen then provided 'Click here' button(s), so that animation could highlight the text information (e.g., the 'Click here' button made visible three red lines on top of the triangle image to highlight the lines defining the shape.) This was followed by a second set of properties (e.g., a triangle has three angles) and the option to click here to view the three animated angles. Sub definitions were then provided (e.g., a triangle that has three equal sides is called an *equilateral triangle*. A triangle with at least two equal sides is called an *isosceles triangle*.) After each shape was defined and animated, calculation of the perimeter of shapes was: (1) explained (e.g., "The perimeter is the length and measurement around a shape. To calculate the perimeter of any shape, add up the length of all the sides."), (2) animated through the use

[1] For research purposes, the software program for the instructional task can be obtained from the first author.

of the ‘click here’ button, and (3) demonstrated with worked examples of calculating the perimeter using numbers in a number sentence).

Difficulty level

The difficulty of the problems increased from the first to the 17th screen, with difficulty defined as the complexity of the shapes. That is, earlier items (descriptions and calculations of simple shapes, such as a square) were followed by more complex shapes and problems involving application of basic items (i.e., descriptions and calculations of complex shapes, such as a cube). The first half of the test items were identified as *basic* and second half as *advanced* items, each of which also increased in calculation difficulty from calculating the perimeter of a rectangle to calculating a perimeter of a cube.

These difficulty judgments in the pre- and post-tests and in the instructional task were reviewed for agreement on item difficulty by general educators making comparison against national state curriculum.

Conditions

The text information and color remained the same in each condition as presented in the first half of the lesson for the basic items (Tutorial slides 1–9). Thus, the plane figures (such as triangles & squares) were shown the same in both conditions without light sources. Only during the second half of the lesson during the advanced problems (Tutorial Slides 10–17) with the more difficult 3D objects (rectangular prisms, cones, cylinder, cube) were conditions differently represented depending on the condition randomly assigned. That is, supporting images within the instructional material were based on the assigned condition: Control: Images-with Low Visual information (Images-LVI) versus Experimental: Images with High Visual information (Images-HVI).

Images-HVI were images that represented 3D solid geometric shapes with a range of values (gradient), thus providing additional visual cues, such as information that may obtained from the light source (gradient, contrasts, transparency, illuminations, shadows and/or highlights, Fleming and Bulthoff 2005). In Fig. 1, see lower figure.

Images-LVI, in the control condition, were defined as images that represented 3D solid geometric shapes with no transitional value (i.e., single value), which lacked information from the light source (gradient, contrasts, transparency, illuminations, shadows and/or highlights, Fleming and Bulthoff 2005). These images of 3D solid geometric shapes were presented from a two-point perspective, which is how humans perceive depth of 3D objects in the absence of additional information (e.g., contrasts). In other words, without additional information from the light source we ‘correct’ for possible distortion (see top figure In Fig. 1).

Design

The participants were randomly assigned to one or the other condition (control or experimental) and to the order of the equivalent pre/post test forms, A or B first, with the constraint that an equivalent number of participants from each group were assigned to each condition and received test form A first and form B second or the reverse order.

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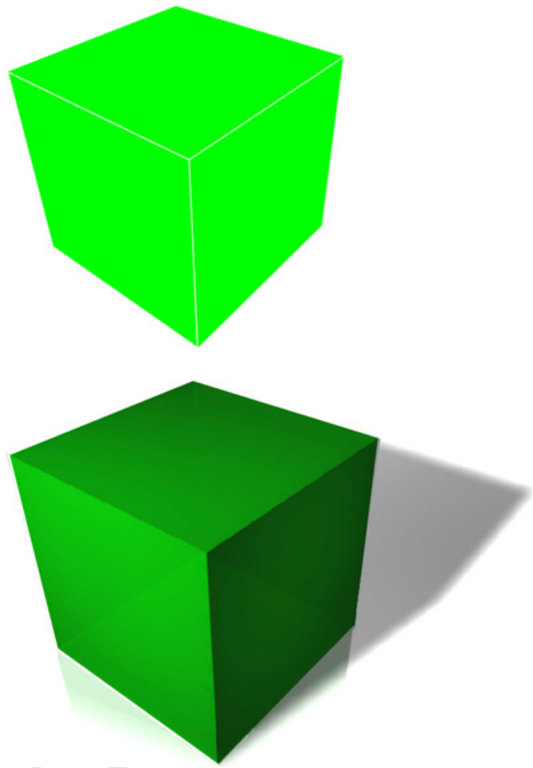

Fig. 1 The top image represents an example of images in the Images-LVI condition; the lower image represents an example of images in the Images-HVI condition

Dependent measures

Performance

Performance measures consisted of the number of problems completed correctly at pre- and post-test divided by the number possible or percent correct.

Behavior

Recordings of the participants' time-on-task behavior were collected using a coding sheet set in 5-s intervals over the 20 min observation period. The following three types of behavior were mutually exclusive with on-task behavior (adapted from Zentall et al. 1994, in an assessment of mathematics performance): (1) talking and noise-making that included inappropriate noises or verbalizations not related to the task (i.e., clear audible sounds such as a whistle, but not a cough, sneeze, or tapping feet), (2) visual off task behavior, defined by students turning their heads more than forty-five degrees away from the computer monitor, (3) torso movements defined as leaning forward or backward, leaving the chair, or twisting the body forty-five degrees or more to look around, and limb movement recorded when participants moved their arms for any reasons other than pressing the computer keyboard or the click of the mouse button.

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Inter-rater reliability

Additional observers were recruited and trained in behavioral observation using video recordings of students interacting with mathematics software on a computer monitor. Cohen's kappa method was used to calculate reliability between observers (Cohen 1988). Cohen has recommended that a power of .80 should be the minimal standard in any setting. Training was continued until there was 80% agreement on the behavioral recordings between the primary and secondary observer. At that point, 80% of the participant sample was selected for concurrent observation of the primary and secondary observer (naïve with respect to group status and condition). The frequency of on-task behavior had a mean inter-observer agreement of 96.4% (range from 87.5% to 100%).

Results

Performance data

Pretest scores

An examination was made of differences among groups in pretest geometry performance. This analysis indicated that the three groups were equivalent in geometry performance—comparisons ($M = 52\%$, $SD = .23$) ADHD-I ($M = 65\%$, $SD = .17$) ADHD-C ($M = 63\%$, $SD = .20$), $F(2, 16) = .58$, $p = .573$.

Post test data

Performance errors were analyzed using a mixed design analysis of covariance (ANCOVA). The pretest scores were used as the covariate, even though groups did not differ at pretest, due to the spread of grades and thus of achievement levels. The between factors were population groups (hyperactive/inattentive, inattentive, and comparison) and conditions (Images-LVI and Images-HVI) and the within factor was difficulty level (basic vs. advanced problems). ANCOVA can be seen as a form of "what if" analysis, asking what would happen if all cases scored equally on the covariates (reducing variability), so that the effect of the factors over and beyond the covariates can be isolated. This was important when predicting differential group responses to an intervention in a relatively small *n* study that employed a range of grade levels (2nd through 4th graders).

Simple effects and planned group contrasts were conducted to determine the nature of significant effects. That is, effect sizes indicate the relative importance of effects and were calculated estimates with an eta-squared value, η^2, which can be interpreted with values of .01 to .05, representing small effects, .06 to .13, representing medium effects, and .14 or greater, representing large effects (Cohen 1988).

These analyses did not yield main effects (see Table 1). However, there were interactions. "When our tests have revealed an interaction in our data we must adjust our interpretation of the means. What this usually implies is that we look separately at the effects of one factor at the individual level of the other factor—the simple effects—systematically determining which are significant and which are not….We use the simple effects and contrasts based on them to help us *understand* and *interpret* what the interaction tests tell us (Keppel and Wickens 2004, p. 246–248." The interaction between difficulty level and group fell short of the conventional level of significance. Because the

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Table 1 Analysis of variance for the performance error data

Source	df	F	MS	p	η^2
Between subjects					
Pre covariate	1	127.46	10009.75	<.0001	1.237
Group (G)	2	1.07	84.08	.376	.021
Condition (C)	1	2.56	201.06	.138	.025
G × C	2	2.50	196.33	.127	.049
Error	12		(78.53)		
Within subjects					
Difficulty (D)	1	2.34	81.67	.155	.010
D × Pre	1	.03	1.05	.865	.000
D × G	2	3.02	105.64	.090	.026
D × C	1	12.39*	432.72	.005	.053
D × C × G	2	2.23	77.81	.154	.019
Error	12		(34.93)		

Values enclosed in parentheses represent mean square errors

* $p < .05$

study was underpowered, with possible Type II error (failing to detect real differences) we followed up this interaction with simple effects. The analysis in the advanced problem data yielded a condition effect, $F(1, 11) = 12.59$, $p = .005$, $\eta^2 = .053$, a small effect size) indicating that all the students performed better in the HVI condition of the advanced problems, see Fig. 2.

More importantly, we documented a significant group by condition interaction ($p = .035$, $\eta^2 = .050$, a small effect size) see upper figure in Fig. 3. Group contrasts indicated that the group of students with hyperactivity/inattention ($M = 76.57$ $SD = .15$) had a greater mean percent correct than comparison students ($M = 57.69$ $SD = .21$) only

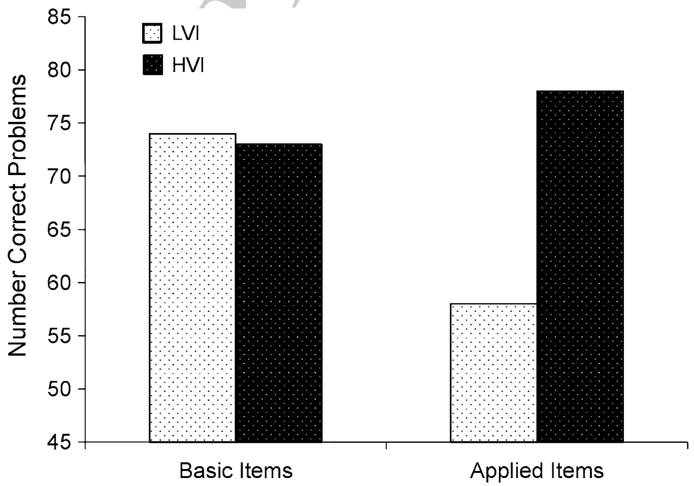

Fig. 2 Number correct scores on easy items and difficult items during performance in the Images-LVI and Images-HVI conditions

in the HVI condition ($p = .004$, $\eta^2 = .16$, a large effect size). Furthermore, condition contrasts were significant for the inattentive group ($p = .043$, $\eta^2 = .22$, a large effect size), who demonstrated better performance on advanced problems in the Images-HVI ($M = 76.57$ $SD = .14$) than in the Images-LVI condition ($M = 51.57$ $SD = .16$), with a nonsignificant gain for the hyperactive group ($p = .177$, $\eta^2 = .06$, a medium effect size).

On-task behavior

The behavioral data were coded (present/absent) each 5-s interval over the 20-min observation period, recorded as the percentage of intervals that on-task behavior occurred (i.e., mutually exclusive with the three types of off-task behavior), and then square root transformed to adjust the data for outliers. For the square root on-task behavior, a 3 group by 2 condition ANOVA was used (the difficult level factor was not available for this analysis), with similar follow up analyses (see Table 2). Although there were no main effects or interactions, the group by condition interaction was plotted due a priori predictions (see Fig. 3, lower figure).

Discussion

Students with inattention or hyperactivity/inattention (at-risk for ADHD) in general education settings typically underachieve in mathematics in spite of average IQ scores. This underachievement is not related to skill deficits but has been attributed to difficulty sustaining attention, holding information in mind (i.e., working memory), and focusing attention to relevant underlying problem elements (concepts). For these students at-risk for a diagnosis of the inattentive and for the combined subtype of ADHD, our predictions were that they would show greater gains than their peers learning new mathematical information if that new information were presented with salient information added. In this study, the added information included transitional values and information from the light source (gradient, contrasts, transparency, illuminations, shadows and/or highlights), which were compared to a control condition with geometric figures with only a single color value and no information from light sources.

Our findings related to the above predictions were documented in an interaction between difficulty level and condition (i.e., levels of graphic intensity/salience). Follow-up analyses of this interaction indicated that performance was improved only in the Images-HVI condition during the advanced application problems, where differences between conditions were applied (i.e., in lessons 10–17—the 'applied' or advanced problems). That is, learning new mathematical material (more complex, 3D, less familiar shapes and their calculations) can be improved by more intense graphical information, as long as the added information does not involve increased working memory requirements. In support of a priori predictions, these gains were attributable to the at-risk students. Group contrasts indicated that (a) the inattentive group demonstrated significantly better performance in the Images-HVI than in the Images-LVI condition with a large effect size, and (b) the combined hyperactivity/inattentive group performed significantly *better than* the comparison group in the Images-HVI condition with a large effect size. Taken together, students with hyperactivity/inattention performed equivalently to their peers during pretest, yet performed significantly better than their peers in response to intense graphic information.

Performance gains that surpass those of typical students do not stand alone in the literature. Students at-risk for ADHD have been documented to perform better than

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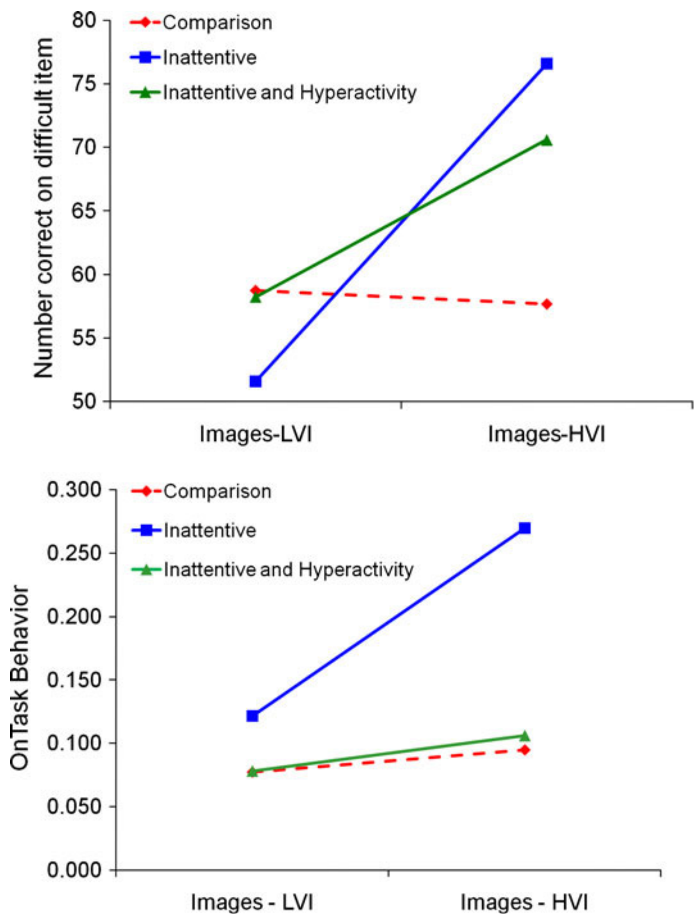

Fig. 3 The top image represents the number correct scores in each condition (Images-LVI and Images-HVI) for each group (comparisons, hyperactive/inattentive, or inattentive) during the performance of difficult items; the lower image represents isomorphic data for the square root on-task behavioral scores for each group in each image condition summed across difficult and easy problem performance

Table 2 Analysis of variance for on-task behavior

Source	*df*	*F*	*MS*	*p*	η^2
Between subjects					
Group (G)	2	1.78	.018	.210	1.789
Condition (C)	1	1.76	.017	.209	1.785
G × C	2	.62	.006	.553	2.635
Error	12		(.009)		

* $p < .05$

performance-matched peers when color was added to relevant details of simple tasks (e.g., in spelling, art, copying/handwriting tasks, for review see Zentall 2005). The current findings extend this prior research by demonstrating that even with color equivalently represented in each condition, differential gains for these students can be obtained from stimulus information from the light source (e.g., shadows, highlights).

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These positive gains could be partially attributed to the task setting, which involved a 20 min computer-generated instructional task plus a 15 min pretest and a 15 min posttest. In other words, session length could have taxed the attention of the at-risk group and magnified the effects of the experimental intervention. However, the 20 min tutorial was presented with an optimal computer environment, which provided graphics with color, self-pacing, and well-sequenced instruction. These variables alone can serve as interventions for these children (for review, see Zentall 2005, 2007). Thus, without further research, it cannot be determined whether session length also contributed to the differential gains documented for the at-risk children.

On-task behavior did not yield a significant group by condition interaction, possibly due to variability in the on-task data or to the fact that difficulty level was not a factor in the behavioral analysis (i.e., on-task data were collected across all lessons and not assessed separately into 1–9 basic lessons versus 10–17 advanced lessons where the HVI intervention was applied). Even so, the large effect size of this interaction and visual analysis suggested that in response to the intervention condition, the on-task data were similar *in form* to the performance data for students with inattention (improved with HVI). These possible improvements in on-task behavior were not observed for children in the combined group, whose on-task behavior appears similar to typical comparisons in response to conditions. The disparity between the *p* and ES values can occur when the independent variable has a strong effect on the dependent variable (large ES), without the ability to detect this effect (nonsignficant *p* values), when there is a small sample or high within-group variability.

Limitations

There are limitations of this study. That is, we did not obtain descriptive data on our samples because of school privacy rules (e.g., on medication status, reading and IQ scores, prior clinical diagnoses). Furthermore, we expected to find pretest differences in geometry. The failure to find group differences *cannot* be explained by ceiling or floor effects, but the pretest may have been insufficiently long to detect differences. Alternatively, the students with inattention/hyperactivity could have natural ability in geometry. Nevertheless, the fact that we did not find initial group differences in performance also refutes possible differences among groups in IQ or reading skill.

There are also study limitations due to sample size. Additional significant findings could have been documented with a greater number of participants and increased statistical power. That is, with a small sample size, we risked Type II errors (false negatives), and we were unable to assess achievement level as a possible moderating factor (i.e., greater gains in response to intervention for students with lower or higher achievement). However, this was a preliminary study assessing a novel manipulation of graphic intensity, and Type II error was a calculated risk (i.e., based on statistical differences with similar groups of students in response to added color stimulation and even smaller sample sizes) (for review of color stimulation effects, see Zentall 2005)." In an underpowered study, it is also possible to increase power (post hoc) by reducing within group variability (e.g., covariate analysis) or adopting a more lenient alpha = .10 or .15. This was unnecessary in this study, because we did find statistical significance.

However, some might further argue that a small sample size does not warrant a ready interpretation of those significant effects that were obtained. For this reason, effect sizes for each analysis were computed, as per APA (1994, p. 18). The significant gains documented in the high intensity condition were supported by large effect sizes, supporting the educational importance of these findings for students with hyperactivity/inattention.

Finally, there are restrictions related to the generality of this intervention, which must be interpreted within the instructional context of the study (i.e., the HVI condition was applied in the latter half of instruction). Thus, the gains observed for the hyperactive/inattentive group in response to the HVI condition was during the advanced application problems *after* earlier instruction with more basic problems and calculations.

Educational implications

Overall, students with attentional problems performed better on advanced geometry problems (e.g., calculation of complex shapes) with visually intense images than with low intense images. Those students with both hyperactivity and inattention performed even better than the comparison group in the Images-HVI condition. Furthermore, this research provided an instructional program in the area of geometry for students with mild disabilities when software programs have been only available in the areas of computation, money, measurement, and algebra (Bryant and Bryant 2003). Instructional programs in geometry may be particularly important in that geometry has increased in importance over the years (Mistretta 2000), perhaps due to its role in fields that require technical competence (e.g., mathematics, science, graphics, engineering). Thus, the practical implications of these findings are that visually intense images can be especially helpful during new learning and could provide the basis for instructional programming and development, especially for diverse learners (i.e., by increasing relevant information without also increasing the requirements for working memory).

Acknowledgments We are very grateful for the assistance provided by Terry Burton. We also express our sincere appreciation to the administrators, teachers, parents and children of the Tippecanoe School Corporation, the Lafayette School Corporation, the West Lafayette School Corporation and the St. Mary's Cathedral School who made this study possible. We also thank Harcourt Achieve for allowing us to use materials from the Student Edition of Saxon Textbook.

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