EFFECTS OF ENVIRONMENTAL STIMULATION ON STUDENTS DEMONSTRATING BEHAVIORS RELATED TO ATTENTION DEFICIT/HYPERACTIVITY DISORDER: A REVIEW OF THE LITERATURE

Brooks R. Vostal
Bowling Green State University

David L. Lee
The Pennsylvania State University

Faith Miller
University of Connecticut

Behaviors characteristic of attention deficit/hyperactivity disorder (ADHD) often interfere with students' and their classmates' learning, and interventions targeting these behaviors may be particularly important in schools. This article reviews studies in which researchers manipulated environmental stimulation during task presentation with school-age students displaying symptoms of ADHD. Using optimal stimulation theory (Zentall, 1975; Leuba, 1955) as a theoretical framework, studies were examined to determine the tasks, intensity, dependent variables, and stimulation topography. Results indicated that the impact of visual stimulation on academic tasks has been the most frequently examined phenomenon in studies meeting inclusion criteria. Stimulation typically improved academic productivity and reduced nonacademic activity; novel stimuli produced initial effects that attenuated during sessions. Implications for intervention and future research directions are suggested.

Attention-Deficit/Hyperactivity Disorder (ADHD) affects children worldwide; estimates suggest that anywhere from .85% to 10% of children and adolescents may be diagnosed with ADHD (Seixas, Weiss, & Miller, 2012). Internationally, children who have been diagnosed with ADHD are likely to have comorbid disorders, including a variety of mental health problems (e.g., anxtiety disorders, depressive disorders) as well as learning problems (Ter-Stepanian, Grizenko, Zappitelli, & Joober, 2010). In learning, for example, some evidence indicates that regardless of native language, children diagnosed with ADHD are likely to have deficits in reading (Alvarado, Puente, Jimenez, & Arrebillaga, 2011). In the United States, estimates between 3% and 5% of the school-age population are accepted (Barkley, 2006), and many of these students qualify for accommodations and/or services under Section 504 of the Vocational Rehabilitation Act or the Individuals with Disabilities Act (IDEA; Reid & Katsiyannis, 1995). Worldwide, the large numbers of students who present ADHD symptoms suggests that educational professionals need effective strategies to address behaviors related to the disorder.

Behaviors symptomatic of ADHD include hyperactivity, impulsivity, and inattention (Barkley, 2006), and ADHD has been linked to academic underachievement (Barry, Lyman, & Klinger, 2002; Raggi & Chronis, 2006). This underachievement may result from performance deficits, rather than skill deficits (Reid, Trout, & Schwartz, 2005). Stated differently, students with ADHD may possess the skills necessary for academic achievement, but fail to persist long enough at tasks in order to display those skills. Without intervention, hyperactive-impulsive behaviors often interfere with students'–and their classmates'–learning (DuPaul, 2007). These behaviors reduce opportunities to learn, inhibit school engagement, and may contribute to students with the most severe symptoms of ADHD demonstrating a higher probability than peers of dropping out of school (Frazier, Youngstrom, Glutting, & Watkins, 2007).

Explanations of ADHD
International researchers have attempted to explain the characteristics that underlie ADHD. Some of these explanations have focused on cognitive theories. For example, *executive dysfunction theory* suggests that structural, functional, and biochemical abnormalities in neural networks (Johnson, Wiersema, & Kuntsi, 2009) lead to deficits in attention-related problems of working memory and response inhibition (Barkley, 1997; Kuntsi & Stevenson, 2000). *Delay aversion theory* (Sonuga-Barke, 1994) and *dual pathway theory* (Sonuga-Barke, 2003) suggest that ADHD-related deficits hinge on aversion to delayed rewards. In classrooms, where grades and other rewards are often separated by the passage of time from task completion, students with ADHD may find this delay particularly aversive.

Other theories suggest that symptoms of ADHD are grounded in children's physiological arousal. For example, *state-regulation theory* suggests that impulsivity serves a sensation-seeking role (Van der Meere, 1996). *Moderate brain arousal* suggests that persons with ADHD are hypersensitive to environmental stimuli, and either too much or too little attenuate cognitive performance (Sikström & Söderlund, 2007). Both can be viewed as extensions of *optimal stimulation theory* (Zentall, 1975, Leuba, 1955), which suggests that behaviors associated with ADHD help those individuals achieve a global state of arousal.

Optimal Stimulation Theory
Optimal stimulation theory (OST) proposes that organisms maintain an optimal level of stimulation through stimulation-seeking activity. Zentall (Zentall, 1975; 2005) proposed that a wide focus of attention and increased activity served self-regulatory purposes for students demonstrating behaviors associated with ADHD. Essentially, OST suggested that individuals seek input when stimulation falls below optimum; much the same way organisms search for food when hungry, they search for stimulation when under-stimulated (Zentall, 1977). Thus, stimulation-seeking behaviors could be viewed as adaptive, and OST provided a rationale for counteracting hyperactivity, impulsivity, and inattentiveness through increased stimulation.

ADHD and OST in the Classroom
Traditionally, school-based treatment for students with ADHD focused on reducing environmental distractions (e.g., place students away from windows; remove colorful bulletin boards, limit physical activity; Reid, 1999). Predominantly, however, these strategies were not found to have empirical support (Conners, 2000).

Internationally, some authors suggest that schools are not well prepared to address the needs of children with ADHD (Ek, Westerlund, Holmberg, & Fernell, 2012). It is possible that OST, the basic physiological patterns that it explains, could provide some direction for school-based interventions. When developing programs for students with ADHD, OST suggested that rather than reducing stimulation, it should be increased (Zentall, 1975). Students with ADHD might achieve optimal stimulation through: (a) stimulant medication (e.g., methylphenidate), (b) physical activity, or (c) sensory input (Zentall & Zentall, 1983). Certainly, stimulant medication has been shown to be effective for individuals with ADHD on measures of behavior (e.g., inattention, impulsivity, hyperactivity; Forness & Kavale, 2001), and OST suggests medication may increase overall arousal. Heightened arousal may increase the likelihood that a person obtains sufficient stimulation from the typical environmental. Nevertheless, stimulant medication and decisions about who receives it are typically beyond teachers' control (Trout, Lienemann, Reid, & Epstein, 2007). While they may be asked to complete inventories concerning medication as part of diagnosis and treatment, teachers do not have the expertise to make recommendations (Snider, Busch, & Arrowood, 2003). On the other hand, physical and sensory stimulation in the classroom *are* within teachers' control. Coupled with reports that many parents and teachers prefer behavioral interventions over stimulant medication (DuPaul, 2007), interventions providing added stimulation could benefit students with ADHD.

To that end, the purpose of this review was to examine studies with school-age children with ADHD-like behaviors (i.e., inattention, impulsivity, hyperactivity) in which environmental stimulation was added during tasks. To describe studies, we asked what tasks students were given, how many sessions were provided, and what variables were measured. Then, to determine if added environmental stimulation produced positive effects on students' productivity and activity, we asked what kind of stimulation was manipulated (e.g., visual, auditory) and what effects were recorded on behavior and academic outcomes.

Method

Studies met five criteria. First, studies were published in peer-reviewed, English-language journals between 1975 (i.e., the year Zentall proposed OST) and 2011. Second, participants were between 5-18 years old (i.e., representative of students' ages in most classrooms), possessed at least average intellectual functioning (i.e., representative of students with or at-risk for high-incidence disabilities), and were diagnosed with ADHD (or appropriate DSM diagnosis for the time the study was published) *or* displayed behaviors typical of ADHD and were identified for the study through the use of standardized rating scales often used as part of an ADHD diagnosis (e.g., Conner's Rating Scale for Teachers; Conners, 1969). Studies including participants with co-morbid emotional disturbance (ED) or learning disabilities (LD) were included because of the high co-morbidity with ADHD (Crawford et al., 2006; Schnoes, Reid, Wagner, & Marder, 2006). Third, researchers concurrently added environmental stimulation (i.e., auditory, kinesthetic, or visual stimulation) with dependent variable measurement. Dependent variables measured immediately following intervention were considered concurrent (e.g., comprehension questions asked after reading a passage in which stimulation was added). Because the focus of this review was on understanding beneficial aspects of environmental stimulation for students with ADHD applicable in schools, studies in which stimulation matched Sikström and Söderlund's (2007) definition of attention-removing stimuli (i.e., sudden changes in environmental stimuli designed solely to disrupt responding) and those that manipulated inter-stimulus intervals (e.g., altering latency between stimuli) during clinical tasks were excluded. Fourth, dependent variables directly measured operant behaviors. Studies in which respondent behaviors were measured (e.g., eye blinks, event related potentials measured by electroencephalogram) and those that used rating scales were excluded. Fifth, research designs compared stimulation within or between participants. Case studies were excluded.

Search Procedures

To identify studies that fit these criteria, we conducted an electronic search in the databases ERIC and PsychInfo. The terms *attention deficit*, *ADHD*, and *hyperactivity* were initially combined with *visual stimulation*, *auditory stimulation*, and *physical activity*, returning 741 citations. We examined abstracts and procedures for inclusion criteria. Next, we conducted ancestral and descendent searches of reference lists of studies meeting criteria. Finally, we conducted a hand-search of the most recent decade of issues from the following journals, selected because of their prevalence among identified articles: *Journal of Abnormal Psychology, Journal of Abnormal Child Psychology, Journal of Behavioral Education, Journal of Educational Psychology,* and *Journal of Learning Disabilities*.

Interobserver Agreement

We used the point-by-point approach (i.e., number of agreements divided by number of disagreements plus the number of agreements multiplied by 100; Kazdin, 1982) to calculate interobserver agreement for inclusion. From the initial electronic search, 10% (n = 74) of citations were chosen randomly and abstracts reviewed for inclusion by the first author and a graduate student. From the sample identified as meeting criteria during the electronic search, two authors reviewed procedures for 20% (n = 20). Interobserver agreement during both stages was 100%. Finally, authors reviewed all articles identified for inclusion. When disagreements occurred, we discussed the article and reached consensus on inclusion.

Coding

Articles were coded for the following variables: (a) tasks, (b) intensity, (c) dependent variables, and (d) stimulation topography. See Table 1 for coding definitions.

Results

The initial electronic search resulted in 101 studies that presented abstracts suggesting they would meet criteria. After authors reviewed procedures for these articles, 37 articles presented 41 separate studies meeting criteria. Table 2 presents a summary of these studies.

Attributes of the Studies

*Tasks***.** Some studies included more than one task, resulting in 45 tasks across the 41 studies (see Table 2). For example, Zentall and Meyer (1987) included both a continuous performance task (CPT) and a word identification task. Academic tasks comprised 53.3% (n = 24) of the studies, including math (i.e., arithmetic), reading (i.e., word identification, passage reading), spelling, and handwriting. Among clinical tasks, vigilance, choice-making, and matching were examined. Among social-recreational tasks, television viewing was most prevalent.

Table 1. Definitions of Coding Variables Used in the Review

Coding Variable	Definition
Tasks	
Academic	Reading, writing, spelling, or math
Clinical	Activity indicative of a psychological construct
Social-Recreational	Interactions with people, leisure activities, or tasks that may be required in school settings, but are not academic
Intensity	Frequency and duration of intervention sessions
Dependent Variables	
Productivity	Frequency or rate of correct responses, attempts, or errors
Activity	Movement, on- or off-task behaviors, or visual attention
Combined	Measured both productivity and activity
Stimulation Topography	
Auditory	Sounds in the environment
Kinesthetic	Physical movement or items to manipulate
Visual Distal	Stimuli not embedded within visual framework of the task
Visual Proximal	Stimuli embedded within visual framework of the task
Combined	More than one form of stimulation added, specifying each

Table 2. Studies Investigating Effects of Environmental Stimulation on Students with ADHD

Authors, Year	Tasks	Intensity	Measures	Topography
Abikoff, Courtney, Szeibel, & Koplewicz (1996)	AC: Math	1 S, 30 min	Pro	AU
Antrop, Roeyers, Van Oost, & Buysse (2000)	SR: Waiting	1 S, 15 min	Act	VD, AU
Antrop, Stock, Verte, & Wiersma (2006)	CL: Choice	2 S	Pro	VD, K
Belfiore, Grskovic, Murphy, & Zentall (1996, Ex 1)	AC: Reading	20 S, 5 min	Pro	VP
Belfiore, Grskovic, Murphy, & Zentall (1996, Ex 2)	AC: Reading	--	Pro	VP
Bailey, Lorch, Milich, & Charnigo (2009)	SR: Television viewing	4 S, 18 min	Com	VD, K
Flake, Lorch, & Milich (2007)	SR: Television viewing	1 S	Com	VD, K
Greenhop & Kann (2007)	AC: Math	2 S, 10 min	Pro	AU
Hall & Zentall (2000)	AC: Homework	23 S, 8-37 m	Pro	VD
Imhoff (2004)	AC: Writing	2 S, 15 min	Pro	VP
Iovino, et al. (1998)	AC: Reading	1 S	Pro	VP
Kercood, et al. (2007)	AC: Math	10 S, 20 min	Com	VD, K
Landau, Lorch, & Milich (1992)	SR: Television viewing	4 S, 7 min	Com	VD, K
Lee & Asplen (2004)	AC: Math	20 S, 10 min	Com	VP
Lee & Zentall (2002; Ex 1)	AC: Math	2 S, 20 min	Com	VP
Lee & Zentall (2002; Ex 2)	AC: Math	2 S, 20 min	Com	VD

Leung, Leung, & Tang (2000)	CL: Vigilance	4 S, 4.5 min	Com	VD
Lorch, Eastham, Milich, Lemberger, et al. (2004)	SR: Television viewing	1 S	Com	VD, K
Lorch, Milich, Sanchez, Vanden Broek, Baer et al. (2000, Ex 1)	SR: Television viewing	2 S, 23 min	Com	VD, K
Lorch, Milich, Sanchez, Vanden Broek, Baer et al. (2000, Ex 2)	SR: Television viewing	2 S, 23 min	Com	VD, K
Lorch, Sanchez, Vanden Broek, Milich Murphy et al. (1999)	SR: Television viewing	1 S, 28 min	Com	VD, K
Radosh & Gittelman (1981)	AC: Math	1 S, 15 min	Pro	VD
Schweitzer & Sulzer-Azaroff (1995)	CL: Choice	6 S, 14 min	Com	VD, K, AU
Shaw, Grayson, & Lewis (2005)	CL: Vigilance	2 S, 14 min	Com	VP
Shaw & Lewis (2005)	AC: Reading	4 S	Com	VP, K
Söderlund, Sikström, & Smart (2007)	CL: Memory	1 S, 45 min	Pro	AU
Steinkamp (1980)	CL: Concept; AC: Math; SR: Coloring	4 S, 60 min	Com	VD, AU, K
Williams, Littell, Reinoso, & Greve (1994)	CL: Problem-solving	4 S	Pro	VP
Zentall (1986)	CL: Vigilance, Concept	2 S	Com	VP
Zentall (1989)	AC: Spelling	1 S, 40 min	Com	VP
Zentall & Dwyer (1980)	CL: Matching	2 S	Com	VP
Zentall, Falkenberg, & Smith (1985)	AC: Writing	2 S, 30 min	Com	VP
Zentall, Grskovic, Javorsky, & Hall (2000)	AC: Reading	2 S, 25-30 min	Pro	VP
Zentall, Hall, & Lee (1998)	AC: Spelling	2 S, 25-40 min	Com	VD
Zentall & Kruczek (1988)	AC: Writing	2 S, 30 min	Com	VP
Zentall & Meyer (1987)	CL: Vigilance; AC: Reading	2 S	Com	VD, K
Zentall & Shaw (1980, Ex 1)	AC: Math	2 S, 25 min	Com	AU
Zentall & Shaw (1980, Ex 2)	AC: Spelling	2 S	Com	AU
Zentall & Zentall (1976)	SR: Waiting; AC: Spelling	2 S, 20 min	Com	VD, AU
Zentall, Zentall, & Barack (1978)	SR: Drawing, naming shapes	2 S	Pro	VP
Zentall, Zentall, & Booth (1978)	AC: Spelling	5 S, 15 min	Com	VP, K

AC= Academic Task; Act = Activity measures; AU = Auditory; CL = Clinical Task; Com = Combined activity and productivity measures; CPT = Continuous Performance Task; Ex = Experiment; K = Kinesthetic; S = sessions; SR = Social Recreational Task; VD = Visual Distal; VP = Visual Proximal

Intensity. Authors of 40 studies reported number of sessions. The shortest session was 4.5 min (Leung et al., 2000) and the longest was 60 min (Steinkamp, 1980). Belfiore, Grskovic, Murphy, and Zentall (1996, Ex 2) did not report number of sessions or session-duration. Only six studies (Abikoff et al., 1996; Belfiore et al., Lee & Zentall, 2002, Ex. 1; Zentall, 1986; Zentall, 1989; Zentall et al., 1985) reported intra-session effects of added stimulation, while others reported effects between sessions.

Dependent variables. Both productivity and activity were measured in 63.4% (n = 26) of studies, while productivity only was measured in 34.1% (n=14), and activity only was measured in one study (Antrop, Roeyers, Van Oost, & Buysse, 2000). Frequently, global observations of on- or off-task behavior (e.g., Shaw et al., 2005) were used. Ten studies reported productivity measures that described task engagement. For example, Abikoff, et al. (1996) measured problems attempted, and Zentall, Falkenberg, and Smith (1985) measured problems completed.

Stimulation Topography

Our primary research question examined stimulation topography and its effects on behavior and academic outcomes. This section reports prevalence of stimulation topography in the reviewed studies and highlights results indicative of those studies within each topography.

Auditory. Auditory stimulation was added in five studies (see Table 2). Abikoff et al. (1996) and Greenhop and Kann (2007) added music while participants completed math problems, resulting in more correct answers. In both studies, participants selected their music. Zentall and Shaw (1980) added spoken words in two studies. When classroom sounds were presented, participants were more active and performed worse on a math task. When recess sounds were presented, students made more errors. Söderlund, Sikstrom, and Smart (2007) added white noise during participants' completion of verbal or physical memory tasks (i.e., participants had to remember a series of spoken sentences that either included physical action or did not). White noise improved correct answers in free recall for participants with ADHD. In sum, constant, low-level sounds (i.e., preferred music, white noise) were beneficial, but distinct sounds (i.e., spoken words) were detrimental to task performance.

Visual Distal. Visual distal stimulation was added in four studies. Radosh and Gittleman (1981) added task-irrelevant borders around math problems, and participants with ADHD made more errors than the control group. Similarly, Lee and Zentall (2002, Ex 2) reported reduced task production when a computer monitor displayed pictures next to a monitor displaying a mathematics task. Mirrors provided visual distal stimulation in two studies (Hall & Zentall, 2000; Zentall, Hall, & Lee, 1998). In Hall and Zentall, two of three participants increased frequency and accuracy of homework completion when mirrors were part of a *learning station* (i.e., a colorful three-sided cubicle containing self-monitoring tools). In Zentall, Hall, and Lee, a mirror was placed on the table in front of students while they worked in a secluded conference room. Participants with ADHD-like behaviors who looked at the mirror increased productivity to a level comparable to participants without ADHD. In sum, stimulation that prompted participants to look away from tasks was detrimental, unless looking away allowed students to view themselves.

Visual Proximal. Visual proximal stimulation was added in 15 studies. Novel colors within tasks were common (see Table 2). For example, Zentall (1989) colored portions of words during spelling. When colored words were presented in the latter half of the session, participants made fewer errors. Similarly, Belfiore et al. (1996; Ex 2) added colors to task-irrelevant chunks of text in a reading task. Participants improved accuracy on comprehension questions early in sessions, but this effect appeared to *wash out* as sessions progressed. In Zentall, Grskovic, Javorsky, and Hall (2000), colors were added to task-irrelevant portions of text, and results showed colors introduced late in reading passages improved accuracy, but not comprehension. Authors of four studies added color and another form of visual proximal stimulation. For example, Zentall et al. (1985) added color and font width to portions of letters during a handwriting task; participants reduced errors initially, but effects washed out.

When color was added evenly to all portions of the task (i.e., rather than specific words or sections) results were mixed. Two studies examined colored overlays in reading (Iovino, Fletcher, Breitmeyer, & Foorman, 1998; Williams, Little, Rienoso, & Greve, 1994). Iovino et al. reported participants with

ADHD improved reading comprehension and word reading, while Williams et al. found no significant effects of colored overlays. Similar to colored overlays, Lee and Asplen (2004) presented math problems on a variety of brightly colored papers and found improved mean digits correct for participants and reduced off-task behavior. Taken together, stimulation embedded within the visual framework of tasks was beneficial when it highlighted task-relevant information or presented some novelty, but initial benefits tended to dissipate within sessions.

*Combined***.** Two stimulation topographies were manipulated in fifteen (36.6%) studies. All studies to manipulate kinesthetic stimulation also manipulated visual distal stimulation. In these studies, participants often had access to toys. For example, during television viewing, Lorch and colleagues (2000, Ex 1; 2000, Ex 2) found participants spent less time looking at monitors when a variety of toys were present. Participants answered more free recall questions with toys present, but fewer causal questions. Conversely, in Kercood, Grskovic, Lee, and Emmert (2007), participants manipulated a single toy while working on a math task; participants were more on-task and answered more problems correctly. In Zentall and Meyer (1987) and Leung et al. (2000) participants committed fewer errors on auditory CPT with added visual distal and kinesthetic stimulation (i.e., participants pressed a button to advance pictures that were unrelated to the auditory task). In sum, when added stimulation included a variety of options, it generally hindered task performance, but when added stimulation was restricted to a single activity, it generally improved task performance.

Discussion

The purpose of this review was to examine effects of environmental stimulation during task completion on students with ADHD-like behaviors. Optimal stimulation theory explained hyperactivity, impulsivity, and inattention as forms of stimulation-seeking behavior (Zentall, 1975). Adding environmental stimulation, therefore, should help students with ADHD to achieve the necessary stimulation to increase productivity and reduce problem activity.

Tasks and Intensity

More than half of the tasks in studies meeting criteria were academic (n = 24), which suggested recognition of the predictable underachievement among students with ADHD (Barry et al., 2002). Writing addressed in these studies, however, included only handwriting, and not tasks related to planning or organizing compositions. While difficulties with transcription are clear among students with ADHD (Imhof, 2004, Tucha & Lange, 2004), the absence of more complex writing tasks provides a clear focus for additional research in this area.

In addition to academics, studies examined social-recreational and clinical tasks. While these tasks may not seem directly applicable to educational interventions, they offer insight into how students with ADHD interact with experiences they encounter in schools. For example, teachers may present instructional videos as a means of extending content coverage. Studies by Lorch and colleagues suggested that physical manipulatives would distract students' attention. Similarly, auditory vigilance studies might be compared to class lectures. Even when provided guided notes, students with ADHD-like behaviors need help attending to relevant stimuli, in much the way participants attended to specific letters in a CPT (e.g., Leung et al., 2000). While results from these studies do not offer evidence for specific educational applications, they inform potential interventions directed at similar school-based tasks. That is, students with ADHD should not have access manipulatives during movies, but during lectures, manipulatives may increase students’ attention.

Also informing potential interventions, the intensity with which stimulation was presented was important. Belfiore et al. (1996, Ex. 2) indicated that stimulation effects dissipated within sessions, speculating that its novelty may have worn off. Of course, novelty itself could be construed as a form of environmental stimulation in which unusual stimuli direct attention (Zentall, 2005). When novelty was embedded within tasks, attention was momentarily directed toward those tasks. Contrary novelty effects that may wash out, Abikoff et al. reported positive effects when student-preferred music was presented early. Overall, these results suggested that students with ADHD-like behaviors habituated to static visual stimulation fairly rapidly, though demonstrated greater task persistence when it was added late, and that auditory stimulation–at least during visual tasks–offered longer-lasting effects.

Stimulation Topography

Results suggested that when environmental stimulation competed with tasks, students’ productivity was hindered. Mirrors and white noise, however, were exceptions. When mirrors created stimulation, students' productivity was not hindered. It is possible that this stimulation served as a form of self-monitoring, prompting students to engage in tasks. When white noise provided auditory stimulation, participants' productivity improved during a listening task. The added low-level auditory stimulation did not appear to distract attention during the auditory task. Of course, it is possible that the white noise blocked other sounds that could have distracted participants, though authors suggested findings were explained best by moderate brain arousal (MBA) created by *stochastic resonance,* noise in the environment that creates beneficial noise within the neural system leading to improved cognitive performance (i.e., Sikström & Söderlund, 2007). Clearly, however, white noise is indicative of added auditory stimulation that does not provide distracting novelty. Taken together, these results suggested that low-levels of stimulation might be beneficial even when experienced through the same sense as tasks.

When stimulation was stronger, however, participants attended to added stimulation more than tasks and productivity suffered. Lee and Zentall (2002) described these results in terms of the *matching law* (Herrnstein, 1961), which states that individuals select one behavior over others based on the amount of reinforcement available contingent on those behaviors. So, if stimulation acts as a reinforcer for students with ADHD, students may be able to access higher levels of reinforcement with less effort from task-competing stimulation, which would decrease engagement in assigned tasks (Lee & Zentall).

When added stimulation and tasks were experienced through *different* senses, however, studies often reported beneficial results. For example, pushing buttons to advance pictures during auditory tasks improved productivity, as did listening to preferred music during math tasks. These benefits were eliminated, however, when multiple sources of stimulation were present. Educational implications seem clear: providing non-competing stimulation outside of tasks could benefit students with ADHD, but only when that stimulation is carefully controlled. Adding sound during written tasks or small-motor activity during listening tasks could be important interventions for students with ADHD, but choices between numerous stimuli would likely distract their attention.

Intervention Implications

Based on the findings of this review, two implications for the use of environmental stimulation were indicated. First, the effects of added stimulation within tasks may be more beneficial when added late to those tasks. Any new task, because of its inherent novelty, might initially offer sufficient stimulation to maintain engagement. For example, a student might engage in a new math task for a short time, but added stimulation later in the task might help him persist. Added stimulation that directs students' attention to task-relevant information is beneficial, but task-irrelevant stimulation–because it is novel–may also offer benefits for students if that stimulation does not force attention away from tasks.

A second intervention implication is that stimulation outside of tasks requires careful pairing between tasks and stimulation topography. Stimulation not embedded in tasks should be experienced through a different sense than that used for task presentation and should be at a consistent level. For example, allowing students with ADHD to listen to preferred music, perhaps through headphones, would be a simple intervention supported by the findings in this review. It would not be entirely clear whether music actually optimized stimulation or blocked out distractions, but from an intervention standpoint this distinction may not matter. When employing kinesthetic stimulation during visual or auditory tasks, it is important that the stimulation involve a single option (e.g., a single manipulative) because multiple options distract attention sufficiently to hinder performance. A single manipulative, however, seemed to promote productive kinesthetic stimulation.

Limitations and Future Directions

Results of this review should be interpreted through consideration of its limitations. First, the diversity of research designs in studies limited our ability to conduct a quantitative synthesis of results. Meta-analysis of the effects of added environmental stimulation would be informative, but because studies often did not include comparable, relevant data (e.g., correlation coefficients among scores for effect size estimates from repeated measures designs), effect size estimation could have been biased, thus rendering results uninterpretable. Second, we did not include studies in which inter-stimulus intervals (ISI) were the sole stimulation manipulated. There is well-documented evidence that persons with ADHD are particularly susceptible to variations in rates of presentation (see Sikström & Söderlund, 2007 for a review), and these rates may change within-task stimulation. Nevertheless, presentation rates of the magnitude shown to affect persons with ADHD (i.e., variations of seconds between stimuli) do not seem to lend themselves to traditional classroom interventions. Third, we did not differentiate between studies that included participants who received clinical diagnoses of ADHD and those who presented ADHD-like behaviors, nor those studies that included participants with co-morbid identifications (e.g., LD and ED). Since the purpose of this review was to identify practices and areas for future research that could be directly relevant in educational contexts (i.e., where strict identification practices may not always be congruent with the variety of students with whom teachers interact) no distinction in diagnostic status of participants was made. This enhanced the external validity of review findings, though it did not identify subtle differences in how participants with differing identifications were affected by environmental stimulation. Finally, the fact that Zentall and her research team conducted the majority of studies may be viewed as a limitation to this emerging research base. However, studies examining arousal-based views of ADHD continue to appear in the literature (e.g., Sikström & Söderlund, 2007; Van der Meere, 1996), and other researchers have explored environmental stimulation directly, and some of these (e.g., Leung et al., 2000) have conducted studies to test the viability of OST specifically.

Even in light of these limitations, results of this review emphasize the need for further research to clarify the benefits of environmental stimulation. On a theoretical level, researchers should continue to rule out other causal mechanisms that may have contributed to results. While experimental control was present in all studies (i.e., functional relations were established between interventions and dependent variables), other theoretical models may add to the validity of OST. For example, effects that could be attributed to novelty may indicate a competing explanation to OST. On the other hand, novel stimuli are certainly a form of stimulation. The fact that the stimulation *washed out* as individuals became accustomed to novelty does not refute that it initially provided stimulation. Future studies should directly test novelty effects to separate them from other forms of environmental stimulation. Similarly, studies showing that mirrors improved performance can be explained through self-management (i.e., the mirrors facilitated a form of self-monitoring) and through OST (i.e., the mirrors provided visual distal stimulation). Future studies could attempt to separate these causal mechanisms in order to direct further intervention development.

Another area of future research might combine added environmental stimulation with other interventions. Studies in this review typically employed minimally intrusive interventions (i.e., adding color to text). If these interventions reduced performance deficits connected with ADHD-like behaviors, could they be added to interventions shown to be effective for instruction? For example, studies by Reid and colleagues (e.g., Reid & Lienemann, 2006; Lienemann & Reid, 2008) have shown that instruction based on self-regulated strategy development (SRSD; Harris & Graham, 1996) benefits students with ADHD. Could added environmental stimulation increase the effects of this instruction? Might added environmental stimulation increase the density of reinforcement during interventions, thus increasing students' task engagement?

Research examining added environmental stimulation within the context of empirically validated instruction offers fertile ground for more effective interventions for students with ADHD. Ultimately, this line of research may demonstrate the most promise. Interventions could incorporate environmental stimulation, harnessing the power of the OST model, while remaining firmly rooted in validated instruction. For example, while listening to preferred music might increase task persistence, it doesn't make students better at math. But introducing preferred music during practice might be helpful. Interventions that combine effective instruction with elements specifically targeting task persistence may best address the performance deficits inherent in ADHD and the skill deficits that may result from co-morbid conditions such as ED or LD.

For now and on a more applied level, added stimulation may provide practitioners with a relatively low effort intervention that can decrease extraneous behaviors and increase task completion. Based on the results of our review the stimulation should not directly compete with task demands, should be added later in tasks (i.e., when inattention is more likely), and should be varied in order to decrease habituation.

References

Abikoff, H., Courtney, M. E., Szeibel, P. J., & Koplewicz, H. S. (1996). The effects of auditory stimulation on the arithmetic productivity of children with ADHD and nondisabled children. *Journal of Learning Disabilities, 29,* 238-246.

Alvarado, J. M., Puente, A., Jimenez, V., Arrebillaga, L. (2011). Evaluating reading and metacognitive deficits in children and adolescents with attention deficit hyperactivity disorder. *Spanish Journal of Psychology, 14,* 62-73.

Antrop, I., Roeyers, H., Van Oost, P., Buysse, A. (2000). Stimulation seeking and hyperactivity in children with ADHD. *Journal of Child Psychology and Psychiatry, 41,* 225-231.

Antrop, I., Stock, P., Verté, S., Wiersema, J. R., Baeyens, D., & Roeyers, H. (2006). ADHD and delay aversion: the influence of non-temporal stimulation on choice for delayed rewards. *Journal of Child Psychology and Psychiatry, 47,* 1152-1158.

Bailey, U. L., Lorch, E. P., Milich, R., & Charnigo, R. (2009). Developmental changes in attention and comprehension among children with attention deficit hyperactivity disorder. *Child Development, 80*, 1842-1855.

Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychological Bulletin, 121,* 65-94.

Barkley, R. A. (2006). *Attention deficit hyperactivity disorder: A handbook for diagnosis and Treatment (3rd Ed).* New York: Guilford Press.

Barry, T. D., Lyman, R., & Klinger, L. G. (2002). Academic underachievement and attention deficit/hyperactivity disorder: The negative impact of symptom severity on school productivity, *Journal of School Psychology, 40,* 259-283.

Belfiore, P. J., Grskovic, J. A., Murphy, A. M., & Zentall, S. S. (1996). The effects of antecedent color on reading for students with learning disabilities and co-occurring attention-deficit/hyperactivity disorder. *Journal of Learning Disabilities, 29,* 432-438.

Conners, C. K. (1969). A teacher rating scale for use in drug studies with children. *American Journal of Psychiatry, 126,* 884-888.

Conners, C. K. (2000). Attention deficit/hyperactivity disorder–Historical development and overview. *Journal of Attention Disorders, 3,* 173-191.

Crawford, S. G., Kaplan, B. J., & Dewey, D. (2006). Effects of coexisting disorders on cognition and behavior in children with ADHD. *Journal of Attention Disorders, 10,* 192-199.

DuPaul, G. J. (2007). School-based interventions for students with attention deficit hyperactivity disorder: Current status and future directions. *School Psychology Review, 36,* 183-194.

Ek, U., Westerlund, J., Holmberg, K., & Frenell, E. (2011). Academic performance of adolescents with ADHD and other behavioural and learning problems–a population-based longitudinal study. *Acta Paediatrica, 100,* 402-406. DOI:10.1111/j.1651-2227.2010.02048.x

Flake, R. A., Lorch, E. P., & Milich, R. (2007). The effects of thematic importance on story recall among children with attention deficit hyperactivity disorder and comparison children. *Journal of Abnormal Psychology, 35,* 43-53.

Forness, S. R., & Kavale, K. A. (2001). ADHD and a return to the medical model of special education. *Education and Treatment of Children, 24,* 224-247.

Frazier, T. W., Youngstrom, E. A., Glutting, J. J., & Watkins, M. W. (2007). ADHD and achievement: Meta-analysis of the child, adolescent, and adult literatures and a concomitant study with college students. *Journal of Learning Disabilities, 40,* 49-65.

Greenhop, K., & Kann, L. (2007). Extra-task stimulation on mathematics productivity in children with and without ADHD. *South African Journal of Psychology, 37,* 330-344.

Hall, A. M., & Zentall, S. S. (2000). The effects of a learning station on the completion and accuracy of math homework for middle school students. *Journal of Behavioral Education, 10,* 123-137.

Harris, K. R., & Graham, S. (1996). *Making the writing process work: Strategies for composition and self-regulation.* Cambridge, MA: Brookline.

Herrnstein, R. J. (1961). Relative and absolute strength of a response as a function of frequency of reinforcement. *Journal of the Experimental Analysis of Behavior, 4,* 267-272.

Imhoff, M. (2004). Effects of color stimulation on handwriting productivity of children with ADHD without and with additional learning disabilities. *European Child & Adolescent Psychiatry, 13,* 191-198.

Iovino, I., Fletcher, J. M., Breitmeyer, B. G., Foorman, B. R. (1998). Colored overlays for visual productivity deficits in children with reading disability and attention deficit/hyperactivity disorder: Are they effective? *Journal of Clinical and Experimental Neuropsychology, 20,* 791-806.

Johnson, K. A., Wiersema, J. R., Kuntsi, J. (2009). What would Karl Popper say? Are current psychological theories of ADHD falsifiable? *Behavioural and Brain Functions, 5.* doi:10.1186/1744-9081-5-15

Kazdin, A. E. (1982). *Single-case research designs: Methods for clinical and applied settings.* New York: Oxford University Press.

Kercood, S., Grskovic, J. A., Lee, D. L., & Emmert, S. (2007). The effects of fine motor movement and tactile stimulation on the math problem solving of students with attention problems. *Journal of Behavioral Education, 16,* 303-310.

Kuntsi, J., & Stevenson, J. (2000). Hyperactivity in children: A focus on genetic research and psychological theories. *Clinical Child and Family Psychology Review, 3,* 1-23.

Landau, S., Lorch, E. P., & Milich, R. (1992). Visual attention to and comprehension of television in attention-deficit hyperactivity disordered and normal boys. *Child Development, 63,* 928-937.

Lee, D. L., & Asplen, J. (2004). Using color to increase math persistence of children with co-occurring learning disabilities and attentional deficits. *Learning Disabilities, 13,* 55-60.

Lee, D. L., & Zentall, S. S. (2002). The effects of visual stimulation on the mathematics productivity of children with attention deficit/hyperactivity disorder. *Behavioral Disorders, 27,* 272-288.

Lienemann, T. O., & Reid, R. (2008). Using self-regulated strategy development to improve expository writing with students with attention deficit hyperactivity disorder. *Exceptional Children, 74,* 471-486.

Leuba, C. (1955). Toward some integration of learning theories: The concept of optimal stimulation. *Psychological Reports, 1,* 27-33.

Leung, J., Leung, P. W. L., & Tang, C. S. K. (2000). A vigilance study of ADHD and control children: Event rate and extra-task stimulation. *Journal of Developmental and Physical Disabilities, 12,* 187-201.

Lorch, E. P., Eastham, D., Milich, R., Lemberger, C. C., Sanchez, R. P., Welsh, R., & van den Broek, P. (2004). Difficulties in comprehending causal relations among children with ADHD: The role of cognitive engagement. *Journal of Abnormal Psychology, 113,* 56-63.

Lorch, E. P., Milich, R., Sanchez, R. P., van den Broek, P., Baer, S., Hooks, K., et al. (2000). Comprehension of televised stories n boys with attention deficit/hyperactivity disorder and nonreferred boys. *Journal of Abnormal Psychology, 109,* 321-330.

Lorch, E. P., Sanchez, R. P., Van den Broek, P., Milich, R., Murphy, E. L., et al. (1999). The relation of story structure properties to recall of television stories in young children with attention-deficit hyperactivity disorder and nonreferred peers. *Journal of Abnormal Child Psychology, 27,* 293-309.

Radosh, A., & Gittelman, R. (1981). The effect of appealing distractors on the productivity of hyperactive children. *Journal of Abnormal Child Psychology, 9,* 179-189.

Raggi, V. L., & Chronis, A. M. (2006). Interventions to address the academic impairment of children and adolescents with ADHD. *Clinical Child and Family Psychology Review, 9,* 85-111.

Reid, R. (1999). Attention-deficit hyperactivity disorder: Effective methods for the classroom. *Focus on Exceptional Children, 32 (4),* 1-20.

Reid, R., & Katsiyannis, A. (1995). Attention deficit-hyperactivity disorder and Section 504. *Remedial and Special Education, 16,*44-52.

Reid, R., & Lienemann, T. O. (2006). Improving the writing performance of students with ADHD. *Exceptional Children, 73,* 53-67.

Reid, R., Trout, A. L., & Schartz, M. (2005). Self-regulation interventions for children with attention deficit/hyperactivity disorder. *Exceptional Children, 71,* 361-377.

Schnoes, C., Reid, R., Wagner, M., & Marder, C. (2006). ADHD among students receiving special education services: A national survey. *Exceptional Children. 72,* 483-496.

Schweitzer, J. B., & Sulzer-Azaroff, B. (1995). Self-control in boys with attention deficit hyperactivity disorder: Effects of added stimulation and time. *Journal of Child Psychology and Psychiatry, 36,* 671-686.

Seixas, M., Weiss, M., & Miller, U. (2012). Systemative review of national and international guideleines on attention-deficit hyperactivity disorder. *Journal of Psychopharmacology, 26,* 753-765. doi: 10.1177/0269881111412095

Sergeant, J. A. (2000). The cognitive-energetic model: An approach to attention-deficit hyperactivity disorder. *Neuroscience & Biobehavioral Reviews, 24,* 7-12.

Shaw, R., Grayson, A., & Lewis, V. (2005). Inhibition, ADHD, and computer games: The inhibitory productivity of children with ADHD on computerized tasks and games. *Journal of Attention Disorders, 8,* 160-168.

Shaw, R., & Lewis, V. (2005). The impact of computer-mediated and traditional academic task presentation on the productivity and behavior of children with ADHD. *Journal of Research in Special Educational Needs, 5,* 47-54.

Sikström, S., & Söderlund, G. (2007). Stimulus-dependent dopamine release in attention deficit/hyperactivity disorder. *Psychological Review, 114,* 1047-1075.

Snider, V. E., Busch, T., & Arrowood, L. (2003). Teacher knowledge of stimulant medication and ADHD. *Remedial ad Special Education, 24,* 46-56.

Söderlund, G., Sikström, S., & Smart, A. (2007). Listen to the noise: Noise is beneficial for cognitive productivity in ADHD. *Journal of Child Psychology and Psychiatry, 48,* 840-847.

Sonuga-Barke, E. J. S. (1994). Annotation: On dysfunction and function in psychological theories of childhood disorder. *Journal of Child Psychology and Psychiatry, 35,* 801-815.

Steinkamp, M. W. (1980). Relationships between environmental distractions and task productivity of hyperactive and normal children. *Journal of Learning Disabilities, 13, 40-45*

Ter-Stepanian, M., Grizenko, N., Zappitelli, M., & Joober, R. (2010). Clinical resppnse to methylphenidate in children diagnosed with attention-deficit hyperactivity disorder and comorbid psychiatric disorders. *Canadian Journal of Psychiatry, 55,* 305-312.

Trout, A. L., Lienemann, T. O., Reid, R., & Epstein, M. H. (2007). A review of non-medication interventions to mprove the academic productivity of children and youth with ADHD. *Remedial and Special Education, 28,* 207-226.

Tucha, O. & Lange, K. W. (2004). Handwriting and attention in children and adults with attention deficit hyperactivity disorder. *Motor Control, 8,* 461-471.

Van der Meere, J. (1996). The role of attention. In S. Sandberg (Ed.), *Hyperactivity disorders in childhood* (pp.111-148). Cambridge: Cambridge University Press.

Wiederholt, J. L., & Bryant, B. R. (1992). *Gray Oral Reading Test 3.* Austin, TX: Pro-Ed.

Williams, M. C., Littell, R. R., Reinoso, C., Greve, K. (1994). Effect of wavelength on productivity of attention-disordered and normal children on the Wisconsin Card Sorting Test. *Neuropsychology, 8,* 187-193.

Zentall, S. S. (1975). Optimal stimulation as a theoretical basis of hyperactivity. *American Journal of Orthopsychiatry, 45,* 549-563.

Zentall, S. S. (1977). Environmental stimulation model. *Exceptional Children, 43,* 502-510.

Zentall, S. S. (1986). Effects of color stimulation on productivity and activity of hyperactive and nonhyperactive children. *Journal of Educational Psychology, 78,* 159-165.

Zentall, S. S. (1989). Attentional cueing in spelling tasks for hyperactive and comparison regular classroom children. *The Journal of Special Education, 23,* 83-93.

Zentall, S. S. (1993). Research on the educational implications of attention deficit hyperactivity disorder. *Exceptional Children, 60,* 143-153.

Zentall, S. S. (2005). Theory- and evidence-based strategies for children with attentional problems. *Psychology in the Schools, 42*, 821-836.

Zentall, S. S., & Dwyer, A. M. (1989). Color effects on the impulsivity and activity of hyperactive children. *Journal of School Psychology, 27,* 165-173.

Zentall, S. S., Falkenberg, S. D., & Smith, L. B. (1985). Effects of color stimulation and information on the copying productivity of attention-problem adolescents. *Journal of Abnormal Child Psychology, 13,* 501-511.

Zentall, S. S, Hall, A. M., & Lee, D. L. (1998). Attentional focus of students with hyperactivity during a word-search task. *Journal of Abnormal Child Psychology, 26,* 335-343.

Zentall, S. S., Grskovic, J. A., Javorsky, J., & Hall, A. M. (2000). Effects of noninformational color on the reading test productivity of students with and without attentional deficits. *Diagnostique, 25,* 129-146.

Zentall, S. S., & Kruczek, T. (1988). The attraction of color for active attention-problem children. *Exceptional Children, 54,* 357-362.

Zentall, S. S., & Meyer, M. J. (1987). Self-regulation of stimulation for ADD-H children during reading and vigilance task productivity. *Journal of Abnormal Child Psychology,15,* 519-536.

Zentall, S. S., & Shaw, J. H. (1980). Effects of classroom noise on productivity and activity of second-grade hyperactive and control children. *Journal of Education Psychology, 72,* 830-840.

Zentall, S.S., & Zentall, T. R. (1976). Activity and task productivity of hyperactive children as a function of environmental stimulation. *Journal of Consulting and Clinical Psychology, 44,* 693-697.

Zentall, S.S., & Zentall, T. R. (1983). Optimal stimulation: A model of disordered activity and productivity in normal and deviant children. *Psychological Bulletin, 94,* 446-471.

Zentall, S.S., Zentall, T. R., & Barack, R. C. (1978). Distraction as a function of within-task stimulation for hyperactive and normal children. *Journal of Learning Disabilities, 11,* 13-21.

Zentall, S.S., Zentall, T. R., Booth, M. E. (1978). Within-task stimulation: Effects on activity and spelling productivity in hyperactive and normal children. *Journal of Educational Research, 71,* 223-230.