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Enhanced Physical Activity Improves Selected Outcomes in Children With ADHD: Systematic Review

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Abstract

This review examines associations between physical activity (PA) and cognitive, behavioral, and physiological outcomes in children with attention-deficit/hyperactivity disorder (ADHD). We reviewed studies on participants ≤18 years old, published in English between January 1998 and December 2014, in PubMed, CINAHL, PsycINFO, and Cochrane Reviews. Twenty-six studies were grouped into two categories: those that did and did not account for effects of ADHD medications. The first category showed lower levels of PA and improved cognitive and behavioral outcomes in youth whose ADHD was treated with medications. The second category showed a positive association between PA levels and cognitive and behavioral outcomes in youth whose ADHD was not treated with medications. For both categories of studies, results were inconclusive regarding physiological outcomes. Randomized controlled trials are needed to better clarify the relationship between PA and outcomes in youth with ADHD, and particularly to understand the impact of ADHD medications on that relationship.

Keywords

physical activity; attention-deficit/hyperactivity disorder; children

Attention deficit hyperactivity disorder (ADHD)—characterized by three classic symptoms of inattention, hyperactivity, and impulsivity—represents the most diagnosed neuro-development disorder in children, currently affecting an estimated 11% of U.S. children age 4 to 17 (Visser et al., 2014). ADHD affects both behavioral and cognitive functioning (e.g., motor skill, executive function) (*The Diagnostic and Statistical Manual of Mental Disorders* [5th ed.; *DSM-5*; American Psychiatric Association, 2013; Shallice et al., 2002]). Moreover, ADHD associates with various co-morbidities including oppositional defiant disorder (35%−60%), conduct disorder (30%−50%), and anxiety and mood disorders (20%−40%) (Faraone, Biederman, & Monuteaux, 2002; Wells et al., 2006).

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Declaration of Conflicting Interests

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Supplemental Material

The online supplemental material is available at http://wjnr.sagepub.com/supplemental.

Presentation of ADHD can be categorized into three types based on symptoms: *predominantly inattentive* (symptoms of inattention are present for the past 6 months), *predominantly hyperactive-impulsive* (symptoms of hyperactivity-impulsivity are present for the past 6 months), and *combined* (symptoms of both inattention and hyperactivity-impulsivity were present for the past 6 months) (5th ed.; *DSM-5*; American Psychiatric Association, 2013).

ADHD Treatment in Children

Among various ADHD treatment options, physical activity (PA) interventions hold promise, but stimulant use (e.g., methylphenidate, dextroamphetamine) and behavioral interventions are by far the prevalent forms of treatment. Pharmacological treatment, the most common treatment modality, has been shown to be associated with improved behavioral outcomes: a decrease in classroom disruption, negative social behaviors, aggression, inappropriate peer interactions, an increase in academic productivity and ontask behavior (Chronis, Jones, & Raggi, 2006), and improved cognitive outcomes with respect to inattention and impulsivity (Swanson, Baler, & Volkow, 2011). While pharmacological treatment has been shown to be effective in 65% to 75% of school-aged children (Greenhill et al., 2002; Halperin, Berwid, & O'Neill, 2014), it is accompanied by adverse side effects such as weight loss, appetite suppression, abdominal pain, headaches, irritability, and tics (De Sousa & Kalra, 2012). Mostly due to these adverse side effects and/ or because families/parents do not find that the medication use is effective (Charach & Fernandez, 2013), a majority of patients prescribed medication stop taking it within the first year (Perwien, Hall, Swensen, & Swindle, 2004; *Song et al.* Sanchez, Crismon, Barner, Bettinger, & Wilson, 2005) and symptoms often return the next day once medication is stopped (Halperin et al., 2014).

The American Academy of Pediatrics Subcommittee on ADHD recommends that in addition to pharmacological treatment, children should also be given evidence-based parent or teacher administered intensive behavior management (Wolraich et al., 2011). Combining medication and behavior management approaches leads to stronger improvement in academic, cognitive, and behavioral outcomes compared with medication alone (Evans, Owens, & Bunford, 2014; Wolraich et al., 2011). Among non-pharmacologic interventions, evidence-based behavioral interventions (implemented by caregivers and/or teachers) have shown the strongest and most consistent benefits (Froehlich, Delgado, & Anixt, 2013). In addition to focusing on children, behavioral intervention often targets parents (Coates, Taylor, & Sayal, 2015), and less frequently other family members (family therapy; Bjornstad & Montgomery, 2005). There is not a great deal of evidence showing the effects of family therapy versus standard care (medication, psychological therapy, or both). One family–school intervention, which incorporated family therapy along with parent group meetings, child group meetings, and family–school consultations, showed improvements in parenting behaviors, homework performance, family involvement in education, and family–school collaboration (Mautone et al., 2012; Power et al., 2012).

However, like pharmacological treatment, behavioral approaches are not without drawbacks. Behavioral interventions are often viewed as burdensome and complex by caregivers and teachers, costly to implement in terms of training, require continued management (Benner-

Davis & Heaton, 2007), and the effects of behavioral management are not sustained after the management interventions are discontinued (Chronis et al., 2004). Finally, neither pharmacological treatment nor behavioral interventions completely normalize attentional, behavioral, and social deficits that characterize ADHD (Hoza et al., 2005; Hoza et al., 2015; Swanson et al., 2001).

As an alternative or supplement to the more common pharmacological and behavioral treatments, interventions that aim to increase PA may also prove effective, without some of the drawbacks of those other two treatment modalities. As ADHD associates with delayed brain development and immature brain function (Casey et al., 1997), it has been suggested that enhanced PA, which has been shown to enhance brain development and function (Shaw et al., 2007; Shaw et al., 2012), may prove a promising alternative modality for treating ADHD. A recent literature review reported a significant negative correlation between enhanced PA participation and behavioral symptoms of ADHD (Reeves & Bailey, 2014). This review, however, was limited by the inclusion of intervention studies only, examined for behavioral outcomes only, and did not examine for the effects of ADHD medication on the relationship between PA and symptoms of ADHD.

Purpose

Overall, this study seeks to examine the association between PA and ADHD (cognitive, behavioral, and physiological) outcomes. In light of epidemiological evidence that children diagnosed with ADHD and who do not take medication are less engaged in PA than those who do take medication (Kim, Mutyala, Agiovlasitis, & Fernhall, 2011), we categorized the studies in this review into two groups based on whether or not the studies accounted for the influence of ADHD medications. We include observational (e.g., cross-s ectional or cohort study) and interventional (experimental) studies. Results of this review add insight into using PA as a strategy to reduce symptoms and related negative outcomes of ADHD, and whether medications play any role in the relationship.

Methods

Search Strategy and Selection Criteria

We conducted a systematic literature review following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Moher, Liberati, Tetzlaff, Altman, & The PRISMA Group, 2009). Four electronic databases—PubMed, CINAHL, PsycInfo, and Cochrane Database of Systematic Reviews—were searched from January 1998 through December 2013 to allow for a sufficient representation of studies on PA and ADHD. The search was updated in December 2014 to include the most recently published studies. The electronic search strategies were executed by two researchers (K.K. for the first round and S.L. for the second round) under the direction of the principal investigator (M.S.) and the librarian (D.L.). Keywords and subject terms used in the search included (a) exercise, abdominal exercises, aerobic exercises, anaerobic exercises, back exercises, calisthenics, group exercise, lower extremity exercises, muscle strengthening, pilates, plyometrics, stretching, physical fitness, PA, or motor activity and (b) ADHD. The search strategy was replicated in each of the four databases.

We included studies that specifically examined relationships between PA and ADHD: by comparing PA level in groups of children with ADHD and non-ADHD groups; by assessing the relationship between PA level and ADHD symptom severity; by testing the impact of PA on ADHD symptom; or by exploring the impact of PA on ADHD treatment. We limited our review to peer-reviewed journal articles; studies written in English; randomized controlled trials, open-label trials, and observational studies (including cross-sectional and cohort studies); and studies including participants under 18 years of age. Studies involving individuals above age 18 were excluded as were studies if they appeared in non-peer reviewed abstracts or meeting proceedings, non-peer reviewed books, and book chapters; single case reports or case studies; narrative reviews of literature or commentaries; and studies with only qualitative outcomes. Additional exclusion criteria that were applied after the initial screening included studies published before January 1998, studies not primarily focused on both PA and ADHD, and studies that did not rely on ADHD diagnosis through application of formal criteria (e.g., *Diagnostic and Statistical Manual of Mental Disorders* [4th ed.; *DSM-IV*; American Psychiatric Association, 1994]) or proxy report (e.g., parents, teachers).

Selection of Studies

A total of 624 potentially relevant studies were retrieved, including 376 from PubMed, 151 from CINAHL, 85 from PsycInfo, and 12 from the Cochrane Database of Systematic Reviews. Two researchers, K.K. and M.N., independently screened all titles and abstracts based on the inclusion and first version of exclusion criteria. Discrepancies were reviewed by the principle investigator (M.S.). After initial screening, 556 results were excluded, and 68 studies were selected for full-text evaluation. Two researchers, K.K. and M.N., independently evaluated the full texts according to the established criteria and the principle investigator arbitrated any disagreements. Through the second level of evaluation, 19 of the 68 studies were selected for the present review. After an updated literature review was conducted in December 2014 following the same procedures described above by researchers S.L. and M.N., and the same principal investigator, an additional four studies were selected from the 69 new search results retrieved. An additional three studies were identified from review of references. Thus, a total of 26 studies are included in this review (see Figure 1 in the electronic supplemental material).

A standardized data extraction form (available on request) was developed and used throughout extraction process. When disagreements between reviewers occurred, consensus was achieved through discussion and/or with a third reviewer (M.S.).

Results

Study Characteristics

This review includes 26 articles classified into two broad categories: studies that did and did not consider ADHD medication effects when examining the relationship between ADHD and PA. In each of these two categories, studies were further divided into observational and intervention studies. Finally, the groups of observational and PA intervention studies were sub-divided again into three outcome domains: cognitive (e.g., executive function),

behavioral (e.g., hyperactive/impulsive symptoms), and physiological (e.g., heart rate or energy expenditure). In total, we identified 20 studies that did not consider the effects of ADHD medication, including nine observational studies and 11 PA intervention studies (abbreviated version, Tables 1–6). The six studies that did consider the effects of ADHD medication included one observational study and five PA intervention studies (abbreviated version, Tables 7–10). Further details about attributions of individual studies, such as information about what criteria were evaluated in the observational and intervention studies, are included in full versions of Tables 1 to 10 in the electronic supplemental materials.

Participant Characteristics

Studies that did not examine for effects of ADHD medications

Observational studies.: Five of the observational studies (Dane, Schachar, & Tannock, 2000; Gapin & Etnier, 2010; Kiluk, Weden, & Culotta, 2009; Lin, Yang, & Su, 2013; Mahon, Woodruff, Horn, Marjerrison, & Cole, 2012) reported sample sizes ranging from 18 to 97 participants; two studies (Ebenegger et al., 2012; Ilott, Saudino, Wood, & Asherson, 2010) had sample sizes ranging from 450 to 622 participants; and two studies (BarnardBrak, Davis, Sulak, & Brak, 2011; Khalife et al., 2014) had larger samples sizes—ranging from 6,934 to 17,565 participants. Ages ranged from 5 to 16 years, except for one study (Ilott et al., 2010) that included preschool-aged children and infants (age range = 2–3). With regard to ADHD diagnosis, five studies reported ADHD diagnosis by a clinician (e.g., using the *DSMIV* criteria; Dane et al., 2000; Gapin & Etnier, 2010; Kiluk et al., 2009; Lin et al., 2013; Mahon et al., 2012). Four studies used a parent or teacher proxy report that used various questionnaires that measure symptoms of ADHD (Barnard-Brak et al., 2011; Ebenegger et al., 2012; Ilott et al., 2010; Khalife et al., 2014). Three studies (Dane et al., 2000; Gapin & Etnier, 2010; Khalife et al., 2014) specified presentations of ADHD while six studies (Barnard-Brak et al., 2011; Ebenegger et al., 2012; Ilott et al., 2010; Kiluk et al., 2009; Lin et al., 2013; Mahon et al., 2012) did not. These studies did not specify types of PA; however, they examined overall amount of PA or amount of PA by intensity (e.g., vigorous, moderate-to-vigorous, sedentary). Duration of PA measured ranged from one, 4-hr period to seven, all-day periods.

Intervention studies.: Sample sizes ranged from 14 to 43 except for one study (Hill, Williams, Aucott, Thomson, & Mon-Williams, 2011) with a larger sample size of 552. The age of participants ranged from 5 to 14 years. Nine studies (Chang, Hung, Huang, Hatfield, & Hung, 2014; Chang, Liu, Yu, & Lee, 2012; Kang, Choi, Kang, & Han, 2011; Lufi & Parish-Plass, 2011; McKune, Pautz, & Lomjbard, 2003; Pontifex, Saliba, Raine, Picchietti, & Hillman, 2013; Tantillo, Kesick, Hynd, & Dishman, 2002; Verret, Guay, Berthiaume, Gardiner, & Beliveau, 2012; Wigal et al., 2003) reported ADHD diagnosis by a clinician (e.g., *DSM-IV* criteria) whereas two studies (Hill et al., 2011; Smith et al., 2013) used a proxy report by parent or teacher with different questionnaires that measure symptoms of ADHD. Four studies (Chang et al., 2014; Chang et al., 2012; Pontifex et al., 2013; Wigal et al., 2003) specified presentation of ADHD, but seven studies (Hill et al., 2011; Kang et al., 2011; Lufi & Parish-Plass, 2011; McKune et al., 2003; Smith et al., 2013; Tantillo et al., 2002; Verret et al., 2012) did not. Study durations varied from 1 day to 10 weeks. Most intervention studies focused on aerobic activity; however, Verret et al. (2012) targeted

muscular activity as well as aerobic activity. Intensity of PA was not clearly mentioned except in one study (moderate-intensity; Chang et al., 2014). Duration of PA ranged from one, 100-min session to 20, 90-min sessions during the school year (not during vacations and holidays).

Studies that did examine for effects of ADHD medications

Observational studies.: There was one observational study with a sample size of 66,707 with age ranging from 6 to 17 years (Kim et al., 2011). The study did not specify presentations of ADHD, and used a proxy report from a doctor or health professional along with reports of medication prescription.

Intervention studies.: Sample sizes ranged from 14 to 49 (Butte, Treuth, Voigt, Llorente, & Heird, 1999; Konrad, Gunther, Heinzel-Gutenbrunner, & Herpertz-Dahlmann, 2005; Mahon, Stephens, & Cole, 2008; Medina et al., 2010; Uebel et al., 2010), with ages ranging from 6 to 15 years. All studies reported that participants were diagnosed with ADHD by a clinician (e.g., *DSM-IV* criteria). Two studies (Konrad et al., 2005; Uebel et al., 2010) specified presentation of ADHD, but three (Butte et al., 1999; Mahon et al., 2008; Medina et al., 2010) studies did not. Study durations varied from 2 days to 2 months.

Studies that did not examine for effects of ADHD medications

Observational studies: Categorized by outcomes.: The majority of these studies examined outcomes in only one out of the three domains (cognitive, behavioral, and physiology), whereas two studies investigated outcomes in one or more domain (Khalife et al., 2014; Lin et al., 2013).

Cognitive domain.: Overall, increased PA positively associates with higher cognitive functioning among ADHD children (Gapin & Etnier, 2010; Lin et al., 2013). PA significantly associated with executive function (R^2 = .23-.28; Gapin & Etnier, 2010) and was negatively associated with abnormal sensory behaviors (i.e., emotional reaction, poor registration, and inattention/ distractibility; r = −.48 to −.52; Lin et al., 2013).

Behavioral domain.: Overall, increased PA positively associates with reduced behavioral symptoms of ADHD (e.g., impulsivity/over-activity; r = .21-.27 or adjusted β = 0.04–8.45; Barnard-Brak et al., 2011; Dane et al., 2000; Ebenegger et al., 2012; Khalife et al., 2014). In addition, Khalife and colleagues (2014) reported a longitudinal positive association between “inattention-hyperactivity” and “inattention” measures at 8 years with physical inactivity at 16 years, as well as a positive association between physical inactivity at age 8 with “inattention-hyperactivity” and “inattention” at age 16 (odds ratio [OR] = 1.60–1.89).

Physiological domain.: Overall, findings showed positive relationships between increased PA and various physiological outcomes (i.e., BMI, genotype, heart rate, and sensory modulation) among children with ADHD are inconclusive (Ilott et al., 2010; Khalife et al., 2014; Lin et al., 2013; Mahon et al., 2012). Khalife and colleagues (2014) reported that PA at 8 years mediated the longitudinal association between inattention-hyperactivity symptoms at 8 years and obesity at 16 years. Ilott and colleagues (2010) found that a

specific genotype—DAT1 SNP rs11564750—significantly associates with increased activity level among youth with ADHD (no effect size was reported), although no comparisons were made to youth without ADHD. Regarding heart rate, Mahon and colleagues (2012) reported that an ADHD group had a higher resting heart rate than a control group (about 11.8 beats per minute), but there was no significant difference in heart rate at peak exercise. Lin and colleagues (2013) reported that PA did not have a significant relationship with sensory modulation (olfactory, auditory, visual, tactile, and vestibular) in ADHD youth (effect size were not reported).

Intervention studies: Categorized by outcomes.: The majority of intervention studies examined outcomes in only one of the three domains—cognitive, behavioral, or physiology —whereas three studies investigated outcomes in one or more domains (Kang et al., 2011; Smith et al., 2013; Verret et al., 2012).

Cognitive domain.: Overall, PA intervention significantly improves cognitive function among children with ADHD, specifically executive function (Chang et al., 2012; Kang et al., 2011), attention (Verret et al., 2012), working memory (Smith et al., 2013), cerebellar function (Smith et al., 2013), cognitive function (Hill et al., 2011), and inhibitory performance, academic performance, and neurocognitive functions (Pontifex et al., 2013). Two studies found statistically significant improvements in inhibitory control after PA intervention (effect size ranges 0.35 to 0.60; Pontifex et al., 2013; Smith et al., 2013). Chang and colleagues (2014) reported improved restraint inhibition in the exercise group, but those improvements were not statistically significant. Three studies reported large effect sizes (e.g., Cohen's $d = 0.57$ [Chang et al., 2012]; Cohen's $d = 0.9$ in the exercise group versus −0.04 in the control group [Chang et al., 2014]; Cohen's d ranges from 0.19 to 1.58 [Pontifex et al., 2013]; Chang et al., 2014; Chang et al., 2012; Pontifex et al., 2013). Hill et al. (2011) reported an exercise group performed better in cognitive function than a non-exercise group (mean difference = 3.85). Two studies (Kang et al., 2011; Verret et al., 2012) did not report their effect sizes.

Behavioral domain.: Overall, PA intervention significantly improved behavioral domain outcomes among children with ADHD. Most studies found that intervention significantly improves ADHD symptoms of inattentiveness (Kang et al., 2011; Lufi & Parish-Plass, 2011; McKune et al., 2003; Smith et al., 2013), hyperactivity (Kang et al., 2011; Lufi & Parish-Plass, 2011; Verret et al., 2012), social skills (Kang et al., 2011; Lufi & Parish-Plass, 2011; Verret et al., 2012), emotional behavior (e.g., anxiety and depression; Lufi & Parish-Plass, 2011; McKune et al., 2003), somatic complaints (Lufi & Parish-Plass, 2011), and problematic behaviors like aggression and interrupting behavior (Lufi & Parish-Plass, 2011; Smith et al., 2013). Of the four studies that included control groups, two studies showed significantly improved behavioral domain outcomes in the intervention group (Kang et al., 2011; Verret et al., 2012) while two studies did not find significant difference between intervention and control groups (Lufi & Parish-Plass, 2011; McKune et al., 2003). Smith et al. (2013) reported medium to large effect sizes (0.40 to 0.78), whereas Lufi and Parish-Plass (2011) reported a small effect size (0.26 to 0.39). The other three studies did not report effect sizes (Kang et al., 2011; McKune et al., 2003; Verret et al., 2012).

Physiological domain.: Effects of PA intervention on BMI, catecholamine response, cardiorespiratory fitness, and motoric functions were inconsistent: PA intervention significantly improved catecholamine response (Wigal et al., 2003) and motoric functions (Tantillo et al., 2002), but did not significantly improve BMI (Verret et al., 2012) and cardiorespiratory fitness measured by heart rate and respiratory function (Verret et al., 2012; Wigal et al., 2003). Tantillo and colleagues (2002) reported faster eye blink responses and reductions in motor impersistence after exercise in boys with ADHD but not in control groups. Wigal and colleagues (2003) examined VO_{2peak} and catecholamine response and reported no difference between the ADHD and control groups in Peak VO_2, while both groups increased catecholamine responses (lactate, norepinephrine, and epinephrine) during exercise. None of the three studies reported effect sizes (Tantillo et al., 2002; Verret et al., 2012; Wigal et al., 2003).

Studies that did examine for effects of ADHD medications

Observational studies: Categorized by outcomes.: Only one medication study reported outcomes in the physiological domain (Kim et al., 2011). Kim and colleagues (2011) assessed BMI among three groups (i.e., ADHD medicated group, ADHD non-medicated group, and control group) and examined associations between PA and obesity. For boys in an ADHD non-medicated group, where “not riding a bike” was an important factor in being obese (OR = 2.11; confidence interval [CI] = [1.22, 3.67]), it was not statistically significant for boys in the ADHD medicated group (OR = 1.54; CI = [0.86, 2.73]). “Not participating in organized sports” was associated with being obese (OR = 1.57; CI = [1.06, 2.34]) for boys in an ADHD medication group while it was not statistically significant for boys in an ADHD non-medicated group (OR = 1.23; CI = [0.81, 1.85]). For girls, “participating in organized sports” and “riding a bike” were not significantly associated with being obese regardless of medication status. For both boys and girls in control groups, “not riding a bike” and “not participating in organized sports” were significantly associated with being obese (OR ranges = 1.27–1.43).

Intervention studies: Categorized by outcomes.: Five intervention studies assessed effects of ADHD medications on outcome domains. Two studies examined outcomes in the behavioral (Medina et al., 2010) and physiology domains (Mahon et al., 2008), whereas three studies investigated outcomes in one or more domains (Butte et al., 1999; Konrad et al., 2005; Medina et al., 2010).

Cognitive domain.: Medications for ADHD significantly improved cognitive function of inhibitory control (Konrad et al., 2005); however, with regards to attention, the findings were inconsistent (Butte et al., 1999; Konrad et al., 2005; Medina et al., 2010). Medina et al. (2010) reported no difference in attention between a medication group and a non-medication group (e.g., Omissions: 22.68 [medication user] vs. 21.55 [non-medication user]), while Butte et al. (1999) and Konrad et al. (2005) found that medication significantly improved attention (Cohen’s $d = 0.15–0.49$). In addition, Butte and colleagues (1999) speculated that stimulant medications contributed to decreased energy expenditure. Medina et al. (2010) provided the mean of cognitive measures in both groups but did not provide a specific effect size such as standardized mean difference between the two groups.

Behavioral domain.: Medication significantly improved behavior outcomes including total ADHD symptoms score (partial η^2 = .33; [Uebel et al., 2010]), hyperactive/impulsive symptoms (effect size of partial η^2 = .08-.22; [Konrad et al., 2005]), and symptoms of inattentiveness (partial η^2 = .08-.19 [Konrad et al., 2005]).

Physiological domain.: Effects of ADHD medications in the physiological domain, such as heart rate, energy expenditure, and respiratory function, were inconsistent (Butte et al., 1999; Mahon et al., 2008; Medina et al., 2010). Medina et al. (2010) reported that a non-medication group had significantly higher heart rates at peak (*mdn* = 195; CI = [199.87, 185.3]) than a medication group (*mdn* = 186.7; CI [203.7, 174.3]). Similarly, Mahon et al. (2008) found significantly higher heart rates at submaximal exercise for a medication group. On the other hand, Butte et al. (1999) found higher heart rates at rest for a medication group and no difference in heart rate during PA. Butte and colleagues (1999) revealed significantly lower energy expenditure in the medication group than the non-medication group (e.g., 4% −5% lower in total energy expenditure [EE] and 6%−7% lower in awake EE), while Medina and colleagues (2010) did not find any difference. The medication group had significant higher oxygen consumption at peak exercise than the non-medication group (1.62 ± 0.26 vs. 1.48 ± 0.22), but there were no significant differences on respiratory exchange ratios (Mahon et al., 2008). None of the studies reported effect sizes (Butte et al., 1999; Mahon et al., 2008; Medina et al., 2010).

Discussion

Overall, the data suggest a positive and significant association between increased PA and decreases in ADHD outcome measures. Based on the analyses of 20 non-medication and six medication studies, the results reveal that in general, PA enhanced cognitive and behavioral outcomes in children with ADHD. However, the results with respect to physiological outcome measures are inconsistent. These findings show general support for PA as a viable intervention strategy for reducing behavioral symptoms and related negative cognitive outcomes of ADHD in children below 18 years of age.

However, methodological constraints in most of the studies limit the ability to draw specific conclusions. Primarily, a lack of prospective and retrospective randomized control studies makes examining for causal mechanisms difficult. Second, a lack of standardized PA measures (wide variety in intensity, scope/type of PA measured across the different studies, and wide duration of PA intervention [ranging from 1 day, 100-min intervention to 20, 90-min weekly sessions over one school year]; Hoza & Smith, 2015) makes comparisons across studies difficult, as does a lack of consistency in effect size measures (some studies did not report effect sizes nor provide information to calculate effect sizes). Third, small sample sizes and significant variation in physiological outcomes measures were another limitation of this review. Finally, the methodological quality (e.g., risk of bias) for the articles included in this review was not formally evaluated. In general, the quality of the studies were relatively low and the scope of the studies small due to the nature of their study design (10 observational, 16 intervention). Increased risk of bias is therefore expected. Beyond applying a comprehensive search strategy to identify potentially relevant studies, in-depth discussions occurred concerning the limitations of each selected study. Studies using

more standardized and robust methodologies would be needed before recommendations can be made with regard to the association of dose, intensity, duration, and scope of PA and beneficial outcomes in children with ADHD.

There is a need for studies to examine separately the impact of PA interventions with children who do/do not take medication and who do/do not receive full-intensity behavioral interventions. In addition, it will be important for research to identify any moderating effects between PA and medication or behavioral interventions (Hoza & Smith, 2015). Studies that control for interaction effects between ADHD medication and PA levels may be particularly important as some existing studies show that ADHD medications result in reduced PA levels in children with ADHD (Butte et al., 1999; Kim et al., 2011; Konrad et al., 2005; Uebel et al., 2010). While medication may be helpful for improving outcomes in youth with ADHD, it is not known if medication negatively impacts the benefits of PA because medication use seems to reduce PA levels. In addition, future studies should carefully account for differences related to presentations of ADHD, severity of ADHD symptoms, duration ADHD diagnosis and age of diagnosis, age of starting treatment/duration of treatment, and absence or a lack of clarity in diagnosis of ADHD (e.g., if only proxy report was used for diagnosis). Finally, to better understand the relationship between PA and ADHD, research examining the confounding effect from severity of ADHD should be conducted; specifically, ADHD medication usage *and* reduced PA levels might both be associated with increased severity of ADHD (as children with significant ADHD are less likely to participate in organized sports).

The following clinical implications appear justified based on this review. The data support the idea that encouraging PA *may* be a viable strategy to improve cognitive and behavioral outcomes for children with ADHD. It seems warranted to encourage parents, pediatricians, child psychiatrists, and/ or other licensed mental health providers to consider inclusion of PA as a part of overall ADHD management. Increased PA may be a particularly effective strategy for youth who are struggling with pharmacological treatments and/ or behavioral interventions. As some studies show benefits from PA on ADHD outcomes and others show that ADHD medications are associated with reduced PA levels, it might be important for health care providers/ researchers to consider that interaction effect when designing medication-based interventions.

In conclusion, there is an immature but growing body of evidence that suggests a positive role of increased PA as a treatment modality for ADHD symptoms, in particularly the cognitive and behavioral domains.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1.

Characteristics of the Observational Studies in the Non-Medication Category: Cognitive Outcome Domain.

Source	*n*	Study Duration	Age Range (*M* ± S*D*)	ADHD Diagnosis	PA Measures/ Days Monitored	IV	Outcome Measures	Medication Effect	Key Results
Gapin & Etnier, 2010	18 (M = 18)	7 days	8–12 (10.6 ± 1.5)	Yes	Yamax accelerometer and PA daily log/7 days	PA	Executive function	No	Sig. positive association between MVPA and TMS/MVPA and TET MVPA was a sig. predictor on TMS/ TET
Lin, Yang, & Su, 2013 *a*	40	7 days	6–12 ADHD/ control (8.6 ± 2.6/9.1 ± 1.8)	Yes	ActiGraph GTIM and PA daily log/ 7days	N/ A	Sensory modulation	No	Sig. negative association between PA and sensory profile: Emotional reaction, poor registration, inattention/ distractibility

Note. ADHD = attention-deficit/hyperactivity disorder; PA = physical activity; IV = independent variable; M = male; Sig. = significant; MVPA = moderate-to-vigorous physical activity; TMS = total move score; TET = total execution time.

a. Indicates study covered more than one domain and results of other domain are listed in their respective tables.

Table 2.

Characteristics of the Observational Studies in the Non-Medication Category: Behavioral Outcome Domain.

Source	*n*	Study Duration	Age Range (*M* ± *SD*)	ADHD Diagnosis	PA Measures/ Days Monitored	IV	Outcome Measures	Medication Effect	Key Results
Barnard-Brak, Davis, Sulak, and Brak (2011)	17,565	1 year	5–7	Inconclusive	PE times/ week and time/ day spent in PE	PE	Symptoms of ADHD	No	PE in Spring 1999 sig. predicts ADHD symptoms in Spring 2000
Dane, Schachar, and Tannock (2000)	64 (M = 49, F = 15)	1 day	7–12 (9.2 ± 1.4)	Yes	ActiGraph/l day	PA	Symptoms of ADHD	No	Sig. positive association between afternoon activity, and inattention symptoms and hyperactivity/ impulsivity symptoms
Ebenegger et al. (2012)	450 (M = 215, F = 235)	Unspecified total study duration	4–6 (5.2 ± 0.6)	Inconclusive	ActiGraph/5 days	PA	Degree of hyperactivity and inattentiveness		Sig. positive association between PA and hyperactivity/ inattention; total count, moderate-vigorous activity, and vigorous activity
Khalife et al. (2014) *a*	At 7–8 years (8,106) At 16 years (6,934)	Not specified	7–16	Inconclusive	At 7–8 years: Preference for physically active play At 16 years: Hours of participating in PA outside of the school	ADHD symptoms Rutter B2 PA at 8 yrs	PA at 16 years ADHD symptoms at 16 yrs	No	Sig. longitudinal associations of inattention-hyperactivity symptoms and physical activity/ inactivity Sig. longitudinal associations of physically active play and inattention symptoms
Kiluk, Weden, and Culotta (2009)	97	Not specified	6–14	Yes	Number of sports participation by a parent	Sports participation	Behaviors: CBCL	No	Sig. negative associations between sports participation and behaviors: A/D, IP, and AP Sig. differences on A/D between groups who played 0 to 2 sports and

Source	*n*	Study Duration	Age Range (*M* ± *SD*)	ADHD Diagnosis	PA Measures/ Days Monitored	IV	Outcome Measures	Medication Effect	Key Results
									those who plays 3 or more sports

Note. ADHD = attention-deficit/h/peractivity disorder; PA = physical activity; IV = independent variable; PE = physical education; M = male; F = female; Sig. = significant; CBCL = Child Behavior Checklist; A/D = anxious depressed; IP = internalizing problems; AP = affective problems,

[a] Stevens and Mulsow (2006).

Table 3.

Characteristics of the Observational Studies in the Non-Medication Category: Physiology Outcome Domain.

Source	*n*	Study Duration	Age Range (*M* ± *SD*)	ADHD Diagnosis	PA Measures/ Days Monitored	IV	Outcome Measures	Medication Effect	Key Results
Ilott, Saudino, Wood, & Asherson, 2010	622	Two visits	2–3 (2.1 ±0.1)	Inconclusive	Minimitteractical (actigraph)/2 days	ADHD symptoms PA	Genotype	No	Total test of association: Sig. association between DATI SNP rs 1 1564750 and activity level in the lab
Khalife et al., 2014 [a]	At 7–8 years (8,106) At 16 years (6,934)	Not specified	7–16	Inconclusive	Preference for physically active play (at 7–8 years) Hours of participating in PA outside of the school (at 16 years)	ADHD symptoms Rutter B2 BMI PA	Obesity BMI (kg/m^2) WHR PA at 16 yrs ADHD symptoms at 16 years	No	At 16 years, sig. negative association between BMI and PA PA at 16 years mediated the longitudinal association between inattention-hyperactivity symptoms and obesity No sig. association between BMI and PA at 8 years and ADHD symptoms at 16 years
Lin, Yang, & Su, 2013 *a*	40	7 days	6–12 ADHD/ control (8.6 ± 2.6/9.1 ± 1.8)	Yes	ActiGraph GTIM and PA daily log/7 days	N/A	SCP: Electro-dermal response in sensory modulation	No	No sig. association between PA and SCP
Mahon, Woodruff, Horn, Marjerrison, & Cole, 2012	45	Two visits	ADHD/ control (11.3 ± 1.8/1 1.2 ± 2.1)	Yes	Peak exercise responses: HR and RPE	ADHD status	Peak exercise responses: HR, power output (W, W/kg), RPE HR-RPE relationship	No	No sig. differences between the groups on peak exercise responses, but the ADHD group had higher HR at rest than the control group The rate of change in HR per unit change in RPE was less in ADHD group

Note. ADHD = attention-deficit/hyperactivity disorder; PA = physical activity; IV = independent variable; Sig. = significant; BMI = body mass index; WHR = waist-hip ratio; SNP = single-nucleotide polymorphism; HR = heart rate; RPE = rating of perceived exertion.

[a]Indicates study covered more than one domain and results of other domain are listed in their respective tables.

Table 4.

Characteristics of the Intervention Studies in the Non-Medication Category: Cognitive Outcome Domain.

Source	*n*	Intervention Duration	Age Range (*M* ± *SD*)	ADHD Diagnosis	PA Measures/ Days Monitored	Outcome Measures	Medication Effect	I&C	Key Results
Chang, Liu, Yu, & Lee, 2012	40 (M = 37, F = 3)	1 day (about 100 min)	8–13 (10.4 ±0.9)	Yes	None	Executive function	No	I: Acute aerobic exercise program C: Watching a running/ exercise-related video	For Stroop word and Stroop color, sig. main effect of time For Stroop color-word, sig. main effect of time and sig. interaction of group by time For the non-perseverative errors in WCST, sig. effect of time and an interaction of group by time For categories completed in WCST, sig. effect of time and an interaction of group by time
Chang, Hung, Huang, Hatfield, & Hung, 2014	27 (M = 23, F = 4)	8 weeks; 2 sessions/ week (90 min/session)	5–10 (8.4 ± 8.3)	Yes	Motor ability:BMAT	Restraint inhibition:Go/ Nogo task	No	I: Aquatic exercise program C: Maintained normal after-school activities	For reaction time/accuracy of Go stimulus, sig. main effect of group For Nogo stimulus, sig. main effect of time and sig. interaction effect of group and time
Hill, Williams, Aucott, Thomson, & Mon-Williams, 2011	552 (M = 295, F = 257)	2 weeks; 1 week for intervention and 1 week for control	8–12 (9.7 ± 1.2)	Inconclusive	None	Cognitive function: CTB	No	I: Exercise intervention for one week C: No exercise intervention for one week	Sig. effect of exercise group in Week 2 on CTB
Kang, Choi, Kang, & Han, 2011 [a]	28	6 week; 2 sessions/ week	Sports-cADHD (8.4 ±0.9) Edu-cADHD (8.6 ± 1.2)	Yes	None	Executive function	No	I: Sports therapy; 90 mins, 12 sessions C: Education	Sig. difference in the changes in digit symbol between two groups Sig. reduced TMT B performance time in Sports-cADHD
Pontifex, Saliba, Raine,	40	3 days	8–10 ADHD-C (9.3 ±	Yes	None	Inhibitory Control Academic	No	I: Exercise C: Reading	Sig. effects of group and session for

Source	*n*	Intervention Duration	Age Range (*M* ± *SD*)	ADHD Diagnosis	PA Measures/ Days Monitored	Outcome Measures	Medication Effect	I&C	Key Results
Picchietti, & Hillman, 2013			0.3) ADHD-I (9.5 ± 0.3) ADHD-H (9.6 ± 0.9) Control (9.8 ±0.1)			performance Data acquisition and procession			response accuracy Sig. effect of exercise session on post error slowing/ reading comprehension and arithmetic Sig. effects of group and session for P3 amplitude Sig. effect of session for P3 latency Sig. effect of group × session for ERN amplitude
Smith et al., 2013 [a]	14 (M = 6, F = 8)	8 weeks; daily for 30 min each day	5.2–8.7 (6.7 ± 1.0)	Inconclusive	None	Pre-post program measures Weekly response inhibition	No	I: PA program No control group	Sig. improvement on part of response inhibition (Shape School Condition B) and inhibition errors (Red Light/Green Light)
Verret, Guay, Berthiaume, Gardiner, & Beliveau, 2012 [a]	42	10 weeks; 3 times per week for 45 min/session	7–12 (9.1 ± l.l)	Yes	Fitness motor tests	Attention functions Response inhibition	No	I: PA training program C: No PA training	Sig. posttest differences in the intervention group on visual research skills and auditory sustained attention

Note. I = intervention; ADHD = attention-deficit/hyperactivity disorder; PA = physical activity; C = control; M = male; F = female; Sig. = significant; WCST = Wisconsin Cart Sorting Test; BMAT = Basic Motor Ability Test-Revised; CTB = Cognitive Test Battery; Sports-cADHD = ADHD group treated with medication and sports therapy; Edu- cADHD = ADHD group treated with medication and education for behavior control; TMT B = Trail Making Test part B; ADHD-C = ADHD combined subtype; ADHD-I = ADHD inattentive subtype; ADHD-H = ADHD-hyperactive/impulsive. P3 = a positive-going deflection in the event-related brain potentials waveform that occurs in response to a simulus; ERN = error-related negativity

[a]. Indicates study covered more than one domain and results of other domain are listed in their respective tables.

Table 5.

Characteristics of the Intervention Studies in the Non-Medication Category: Behavioral Outcome Domain.

Source	*n*	Intervention Duration	Age Range(*M* ± *SD*)	ADHD Diagnosis	PA Measures/ Days Monitored	Outcome Measures	Medication Effect	I&C	Key Results
Kang, Choi, Kang, & Han, 2011 [a]	28	6 week; 2 sessions/ week	Sports-cADHD (8.4±0.9) edu-cADHD (8.6 ± 1.2)	Yes	None	ADHD symptoms Social Skills	No	I: Sports therapy; 90 min, 12 sessions C: Education; 12 sessions	Sig. greater improvements in K-ARS-PT total scores/K-ARS-PT inattention in Sports-cADHD Sig. increased cooperativeness in Sports-cADHD
Lufi & Parish-Plass, 2011	M (28)	20 weekly sessions for 1 school year(90 min) pre/post/ follow-up after 1 year	8–13.5 (10.9)	Yes	None	Behaviors: 1. YSR 2. CBCL 3. ASQ-P by parents 4. ASQ-T by teachers	No	I: ADHD group C: Other behavioral problem group	Sig. higher scores in ASQ-T in the ADHD group than the control group Sig. improvements in ASQ-P/ YSR (anxiety and somatic) for both groups Sig. improvements in CBCL (aggression, anxiety, attention, & social) for both groups
McKune, Pautz, & Lomjbard, 2003	19 (M = 13, F = 6)	5 week; 5 days a week, 60 min of exercise	5–13 1 (10.8 ± 1.9) C (11.2 ± 1.5)	Yes	Physical activity data sheet	Behaviors: Modified version of CPRS	No	1: 60-min moderate-intensity exercise program C: Non-exercise	Sig. improvements in total behavior/ attention/ emotional for both groups
Smith et al., 2013 [a]	14 (M = 6, F = 8)	8 weeks; daily for 30 min each day	5.2–8.7 (6.7 ± 1.0)	Inconclusive	N/A	Problem behaviors (weekly) Negative behaviors (daily) Post: Perceived degree of improvement	No	I: PA program No control group	Sig. improvements on PMCTRS-AC, Iowa I/O, and Iowa O/D Sig. improvement on interrupting behavior 29%−71 % of participants rated as indicating some level of improvement by teachers, parents, and program staff
Verret, Guay, Berthiaume, Gardiner, & Beliveau, 2012 [a]	21 (M = 19, F = 2)	10 weeks; 3 times per week for 45 min each session	7–12 (9.1 ±1.1)	Yes	Fitness motor tests	CBCL	No	I: PA training program C: No PA training	Sig. posttest differences between the intervention and control groups on total CBCL score,

Source	*n*	Intervention Duration	Age Range(*M* ± *SD*)	ADHD Diagnosis	PA Measures/ Days Monitored	Outcome Measures	Medication Effect	I&C	Key Results
									attention/ thought/social problems Sig. improvements on anxiety-depression in the intervention

Note. I = intervention; ADHD = attention-deficit/hyperactivity disorder; PA = physical activity; C = control; Sports-cADHD = ADHD group treated with medication and sports therapy; Edu-cADHD = ADHD group treated with medication and education for behavior control; Sig. = significant; K-ARS-PT = Korean version of the parent and teach version of DuPaul's ADHD Rating Scale; M = male; YSR = youth self-report; CBCL = Child Behavior Checklist; ASQ-P = Conners' Abbreviated Symptom Questionnaire-Parents; ASQ-T = Conners' Abbreviated Symptom Questionnaire-Teachers; CPRS = Conners' Parent Rating Scale; F = female; PMCTRS = Pittsburgh Modified Conners Teacher Rating Scale; I/O = inattention/overactivity; O/D = oppositional/defiant. AC = abbreviated conners

[a] Indicates study covered more than one domain and results of other domain are listed in their respective tables.

Table 6.

Characteristics of the Intervention Studies in the Non-Medication Category: Physiology Outcome Domain.

Source	*n*	Intervention Duration	Age Range (*M* ± *SD*)	ADHD Diagnosis	PA Measures/ Days Monitored	Outcome Measures	Medication Effect	I&C	Key Results
Tantillo, Kesick, Hynd, & Dishman, 2002	43 (M = 21, F = 22)	3 days	8–12 ADHD (M = 9.8 ± 1.6, F = 10.2 ± 1.8) Control (M = 10.3 ± 1.6, F = 9.7 ± 1.6)	Yes	A daily physical activity record	Brain dopaminergic activity	No	I: ADHD C: No ADHD	Sig. diagnosis × Sex × Time × Linear trend for spontaneous eye blinks and $ASER_{AMP}$ Sig. diagnosis × Sex × Time × Quadratic trend for $aser_{LAT}$
Verret, Guay, Berthiaume, Gardiner, & Beliveau, 2012 [a]	21 (M = 19, F = 2)	10 weeks; 3 times per week for 45 min/session	7–12 (9.1 ± l.l)	Yes	Fitness motor tests	1. BMI 2. Resting and maximal HR 3. Flexibility 4. AC	No	I: PA training program C: No PA training	No sig. differences in BMI, resting and maximal HR, flexibility, and AC between groups
Wigal et al. (2003)	18 (M = 18)	Two sessions on different days within a week	ADHD 7–10 (8.4 ± 0.4) Control 7–1 1 (8.6 ± 0.1)	Yes		Peak and end-exercise HR Peak VO_2 Catecholamine response Lactate	No	I: ADHD; newly diagnosed untreated participants C: Healthy age-matched controls	Sig. increased lactate during exercise in both groups Sig. increased NE during exercise in a control group Sig. increased EPI during exercise in both groups; a control group has sig. higher EPI at peak exercise

Note. I = intervention; ADHD = attention-deficit/hyperactivity disorder; PA = physical activity; C = control; M = male; F = female; Sig. = significant; $ASER_{AMP}$ = acoustic startle eye blink response amplitude; $ASER_{LAT}$ = acoustic startle eye blink response latency; BMI = body mass index; HR = heart rate; AC = aerobic capacity; $V0_2$ = oxygen consumption; NE = norepinephrine; EPI = epinephrine.

[a]Indicates study covered more than one domain and results of other domain are listed in their respective tables.

Table 7.

Characteristics of the Observational Studies in the Medication Category: Physiology Outcome Domain.

Source	*n*	Study Duration	Age Range (*M* ± *SD*)	ADHD Diagnosis	PA Measures/ Days Monitored	IV	Outcome Measures	Medication Effect	Key Results
Kim, Mutyala, Agiovlasitis, & Fernhall, 2011 [a]	66,707 (M = 34,157, F = 32,486)	All testing done on one day	6–17	Inconclusive	PA: Participating in vigorous activity 20 min for 3+ days/week	ADHD status ADHD medication status	Obesity	Yes	Among boys in ADHD non medicated group, “not riding a bike” was sig. associated with obesity In control group, “not riding a bike”/ “participating in organized sports” were sig. associated with obesity Among boys in ADHD medicated group, “not participating in organized sports” and “not having enough sleep” were sig. associated with obesity

Note. ADHD = attention-deficit/hyperactivity disorder; PA = physical activity; IV = independent variable; M = male; F = female,

[a]Indicates study covered more than one domain and results of other domain are listed in their respective tables.

Table 8.

Characteristics of the Intervention Studies in the Medication Category: Cognitive Outcome Domain.

Source	*n*	Intervention Duration	Age Range (*M* ± *SD*)	ADHD Diagnosis	PA Measures/ Days Monitored	Outcome Measures	Medication Effect	I&C	Key Results
Butte, Treuth, Voigt, Llorente, and Heird (I999) [a]	31 (M = 26, F = 5)	2 months Study 1: Day 1 Study 2: 2 months after Study 1	6–12 (9.5 ± 1.9)	Yes	Counts per minute by a Doppler microwave detector/19 hr	Attention Energy expenditure	Yes	I (Study 2): Received different doses of stimulant medication C (Study 1): No stimulant medication	Positive sig. correlation between errors of commission and decrease in TEE, AEE, movie EE attributable to the stimulant medication Negative sig. correlation between response time and difference in TEE, AEE, total and awake activity incident to the stimulant medication
Konrad, Gunther, Heinzel-Gutenbrunner, & Herpertz-Dahlmann, 2005 [a]	44 (M = 37, F = 7)	6 days	8–12 (10.3 ± 1.9)	Yes	Actigraph/ 6 days	Attention Inhibitory control	Yes	I: Medication (low dose and high dose) C: Placebo	Sig. effects of MPH on total errors in Sustained Attention Task and SSRT A sig. linear trend of MPH on Sustained Attention Task as well as a sig. quadratic trend for SSRT
Medina et al. (2010) [a]	25 (M = 25)	2 days	7–15 US (9.3 ± 2.9) NUS (9.8 ± 2.4)	Yes	None	Sustained attention	Yes	I: 30-min treadmill exercise protocol C: 1-min stretching session	No sig. differences on CPT between US and NUS samples Sig. faster Hit RT/Hit RT ISI change in the PA group than control Sig. lower perseverations in the PA group than control

Note. I = intervention; ADHD = attention-deficit/hyperactivity disorder; PA = physical activity; C = control; M = male; F = female; Sig. = significant; TEE = total energy expenditure; AEE = awake energy expenditure; EE = energy expenditure; MPH = methylphenidate; SSRT = stop-signal reaction time; US = methylphenidate users; NUS = nonmethylphenidate users; CPT = Conner's Continuous Performance Test; RT = reaction time; ISI = interstimulus,

[a]. Indicates study covered more than one domain and results of other domain are listed in their respective tables.

Table 9.

Characteristics of the Intervention Studies in the Medication Category: Behavioral Outcome Domain.

Source	*n*	Intervention Duration	Age Range (M ± SD)	ADHD Diagnosis	PA Measures/ Days Monitored	Outcome Measures	Medication Effect	I&C	Key Results
Konrad, Gunther, Heinzel-Gutenbrunner, & Herpertz-Dahlmann, 2005 [a]	44 (M = 37, F = 7)	6 days	8–12 (10.3 ± 1.9)	Yes	Actigraph/ 6 days	ADHD symptoms	Yes	I: Medication (low dose and high dose) C: Placebo	Sig. effects of MPH on inattentive, hyperactive/ impulsive, and overall symptoms A sig. linear trend of MPH on inattentive, hyperactive/ impulsive, and overall symptoms Sig. correlations between PA data and inattentive and hyperactive/ impulsive
Uebel et al., 2010	49 (M = 43, F = 6)	2.5 weeks; 4 consecutive working days/week + weekend	8–13 (10.3 ± 1.4)	Yes	Actigraph/ 4 days of each week	ADHD symptoms	Yes	I: Medication (MPH-IR/ MPH-MR) C: Placebo	Sig. treatment effect of medication on ADHD symptoms; improvements of total score and all subscales of ADHD symptoms with MPH-IR and MPH-MR compared with placebo

Note. I = intervention; ADHD = attention-deficit/hyperactivity disorder; PA = physical activity; C = control; M = male; F = female; Sig. = significant; MPH = methylphenidate; MPH-IR = immediate release methylphenidate; MPH-MR = modified release methylphenidate.

[a.] Indicates study covered more than one domain and results of other domain are listed in their respective tables.

Table 10.

Characteristics of the Intervention Studies in the Medication Category: Physiology Outcome Domain.

Source	*n*	Intervention Duration	Age Range (*M* ± *SD*)	ADHD Diagnosis	PA Measures/ Days Monitored	Outcome Measures	Medication Effect	I&C	Key Results
Butte, Treuth, Voigt, Llorente, and Heird (1999) [a]	31 (M = 26, F = 5)	2 months 1. Study 1: Day 1 2. Study 2: 2 months after Study 1	6–12 (9.5 ± 1.9)	Yes	Counts per minute by a Doppler microwave detector/19 hr	HR EE, RQ, HR, and ACT done during discrete activities	Yes	I (Study 2): Received different doses of stimulant medication C (Study 1): No stimulant medication	Sig. lower TEE/AEE with medication Adjusted for activity, no sig. differences in TEE and AEE between two studies Sig. less TEE/RMR and lower TEE/BMR with medication Sig. differences on EE during discrete activities
Mahon, Stephens, & Cole, 2008	14 (M = 14)	3 separate days	9–12 (10.9 ± 1.1)	Yes	None	HR VO_2 V_E/VO_2 RER RPE	Yes	I: Medication C: Non-medication	Sig. higher in VO_2, HR, work rate at peak exercise in medication group No sig. differences in RER or RPE at peak exercise between two groups
Medina et al., 2010 [a]	25 (M = 25)	2 days	7–15 US (9.3 ± 2.9) NUS (9.8 ±2.4)	Yes	None	Oxygen consumption EE HR	Yes	I: 30-min exercise protocol C: 1 -min stretching session	Sig. higher HR peak in NUS than US

Note. I = intervention; ADHD = attention-deficit/hyperactivity disorder; PA = physical activity; C = control; M = male; F = female; HR = heart rate; EE = energy expenditure; RQ = respiratory quotient; ACT = activity; Sig. = significant; TEE = total energy expenditure; AEE = awake energy expenditure; RMR = resting metabolic rate; BMR = basal metabolic rate; $V0_2$ = oxygen consumption; $V_E/V0_2$ = ventilator equivalent for oxygen; RER = respiratory exchange ratio; RPE = rating of perceived exertion; US = methylphenidate users; NUS = non-methylphenidate users.

[a] Indicates study covered more than one domain and results of other domain are listed in their respective tables.