Can Movement Games Enhance Executive Function in Overweight Children? A Randomized Controlled Trial

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Purpose: This study determines the effect of movement games on executive function among overweight children. **Methods:** Forty-four overweight children received an intervention of movement games, and 40 overweight children participated in original physical education lessons. An intervention of movement games was conducted three times a week for 8 consecutive weeks. Neuropsychological tasks and the Stroop and determination tests were assessed pre- and postintervention. **Results:** The results indicated that movement games enhanced the children's performance in the inhibitory control and attentional function, particularly in the interference tendency condition, whereas no performance improvement was noted in the original physical education lessons. **Conclusion:** The findings indicate that movement games can be utilized as a useful intervention for improving the attentional and inhibitory problems of overweight children. School authorities should consider incorporating these activities into programs related to physical and health education.

Keywords: attention function, cognitive benefits, inhibitory control, motor skills

Childhood obesity has become a global problem (Wang, Min, Khuri, & Li, 2017; Yang, Shields, Guo, & Liu, 2018). In addition to correlations between obesity and various health threats, such as hypertension and Type 2 diabetes, research has linked obesity to poor cognitive functioning, particularly in executive function (EF; Volkow et al., 2009; Walther, Birdsill, Glisky, & Ryan, 2009). EF refers to as a family of top-down mental processes that are necessary for the cognitive control of behavior, is self-monitoring or self-regulation behaviors that facilitate the attainment of chosen goals (Chang, Liu, Yu, & Lee, 2012). Studies have shown that EF in children is closely correlated with their academic success, social function, and emotional control (Best, Miller, & Naglieri, 2011; Clair-Thompson & Gathercole, 2006; Eigsti et al., 2006). EF may act as a mediator between overweight children and their intelligence quotient (IQ) test performance (Li, 1995) as well as their academic achievement (Taras & Potts-Datema, 2005). Moreover, emerging literature has presented increased evidence supporting the detrimental effect of obesity on EF, including attention, mental flexibility, reward sensitivity, working memory, and other brain functions (Chang, Chu, Chen, Hung, & Etnier, 2017; Crova et al., 2014; Reinert, Po'e, & Barkin, 2013; Yang et al., 2018) among both children and adolescents. For example, studies have noted that

obesity is related to the dysregulation of these specific limbic neural circuits that are connected to poor inhibition function (Reinert et al., 2013; Willeumier, Taylor, & Amen, 2011). Therefore, the association between obesity and cognition performance in children is frequently related to EF (Pannacciulli et al., 2006). Early intervention strategies are imperative for preventing childhood obesity or relieving its effect on EF during the critical development period of EF (Davis et al., 2007, 2011; Reinert et al., 2013).

Executive function is an umbrella term that consists of several key components (Reinert et al., 2013), including (a) inhibitory control (e.g., controlling impulsive responses using attention and reasoning to respond), (b) attention (e.g., concentrating while excluding other stimuli), (c) mental flexibility (e.g., disengaging an irrelevant task set), (d) reward sensitivity (e.g., engaging in risk-taking behaviors), and (e) working memory (e.g., the ability to remember and use relevant information during an activity). These functions are believed to be key determinants influencing children's overall success in physical education (PE; Kubesch et al., 2009). For instance, during a PE class, if a teacher is demonstrating a skill, such as shooting a basketball, students require good inhibitory control skills to resist the impulse to dribble the ball around. Students must be able to maintain their attention long enough and use their mental flexibility to understand how a basketball can be shot in more than one way; they must also use their working memory to repeat what the teacher has demonstrated. Reward sensitivity can motivate students to continue practicing this newly learned skill. Moreover, studies have suggested that playing while using manipulative motor skills provides a unique opportunity to activate children's EF skills during school-related physical activities (Davis et al., 2011;

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de Greeff, Bosker, Oosterlaan, Visscher, & Hartman, 2018). These results suggest that physical movement is associated with improved EF performance among children; they also allow children to set goals, plan, and complete tasks at school and in their everyday life (Jacobson, Williford, & Pianta, 2011; Verburgh, Königs, Scherder, & Oosterlaan, 2014).

Because physical activity (PA) has been associated with improving EF in overweight children (Vazou & Smiley-Oyen, 2014) and obesity is a marker of chronic inactivity (Must & Tybor, 2005), the effects of PA intervention on EF may be substantial or noticeable among overweight, sedentary children compared with lean, active children (Davis et al., 2007, 2011). In a recent meta-analysis, 31 relevant intervention studies were examined and the positive effects of PA on EF were noted, including interference control, set shifting, consistency in response speed, vigilance, and impulsive control between obese children and preadolescent children (de Greeff et al., 2018). The specific relationship between PA and EF was proposed based on findings that after aerobic exercise intervention, overweight children showed improved performance for EF tasks and increased corresponding activity in the prefrontal cortex (PFC), which is closely related to EF (Davis et al., 2011). Moreover, PFC and EF share paralleled and protracted developmental timetables that mature at some point during adolescence or early adulthood (Best, Miller, & Jones, 2009). This protracted cognitive development may be one of the potential explanations of PA's effects on EF. Best (2010) indicated that both EF and the underlying neural system remain immature during late childhood. PA may facilitate their development or temporarily promote their functioning by supporting neural circuitry (e.g., increased blood flow). Through experiments, Willeumier et al. (2011) showed that an elevated body mass index (BMI) is associated with decreased regional cerebral blood flow in the PFC, and elevated BMI may be a risk factor for decreased PFC function and potentially impaired EF. However, it was also noted that not all forms of PAs equally promote EF performance among children (Best, 2010). Differences in exercise settings can result in diverse effects on different EF domains (Best, 2010; de Greeff et al., 2018). For instance, cognition engaging or complex exercise, which requires controlled and adaptive cognition and social interaction during specific moments or games (e.g., games of basketball or football), showed stronger effects on promoting EF compared with automatic or simple exercise (e.g., treadmill walking; Best, 2010; de Greeff et al., 2018). Therefore, it is concluded that benefits are more substantial for intervention programs that implement continuous and cognitively engaging PA over the duration of several weeks instead of a single bout of aerobic PA (de Greeff et al., 2018). However, studies have not examined the effects of cognitively engaging PA programs on the EF of overweight children.

The current study contributes to the literature regarding three vital aspects, namely PE, overweight children, and EF, by using a modified version of movement games by Davis et al. (2011) as an intervention to examine its effects on two specific EF domains (i.e., inhibitory control and attention function) among overweight children. Studies have shown that the positive effects of PA on children, including the development of social behaviors, self-esteem, and cognitive functions in school PE, have been frequently addressed in the relevant literature (Bailey, 2006; Bailey et al., 2009). We believe that by using a symptom-matched compared group, the benefits of movement games for alleviating the cognitive deficits of overweight children can be further illustrated. Studies using a similar design with a built-in school curriculum are rarely conducted (Crova et al., 2014), thus increasing the potential value

of the current study because it can provide implications for the design of PE curriculum in primary schools. In particular, overweight and obese children are often less active and may have a higher risk of experiencing adverse health-related outcomes, cognitive processes, and mental development (Sahoo et al., 2015). Movement activities in a school setting have considerable potential for improving attention, memory retrieval, determination, problem solving, peer relationship quality, and physical fitness among overweight children (Best, 2010).

These reported benefits of movement games for overweight children were attributed to the improvement of EF and brain activation changes (Davis et al., 2011). Numerous findings have suggested that inhibitory control and attention function can be sensitive indices of baseline cognitive processes and can, therefore, be used to effectively distinguish between overweight and normal-weight individuals (Davis et al., 2011; Huang et al., 2015; Song et al., 2016). Therefore, in this study, changes in inhibitory control and attention function are observed after conducting a movement games program among overweight children. In this study, "inhibitory control" refers to a central component of EF and focuses on the ability to actively inhibit or delay a dominant response to achieve a goal; it is also a measure of selective attention, inhibitory control, cognitive inhibition, or inhibition of a dominant response (Chang et al., 2012). The term "attention function" refers to a central component of EF that distinguishes and identifies multiple stimuli reactions in variables, which provides an understanding of reactive stress tolerance, attention deficits, and reaction speed in the presence of rapidly changing and continuous stimuli (Shmygalev et al., 2011). Thus, the hypothesis was that EF indices of inhibitory control and attention function would be facilitated by movement games. In other words, shorter reaction time latency and increased response accuracy would be observed after an intervention of movement games, relative to original PE classes with improved performance during trials necessitating greater amounts of inhibitory control and attention function. This pattern of results would provide additional evidence that movement games have a disproportionately larger effect on inhibitory control and attention function. To examine the prolonged impact of movement games on inhibitory control and attention function, the Stroop test (i.e., reaction time, response accuracy) and determination test (i.e., correct responses on-time and response accuracy rate) of the Vienna test system were used to assess EF performance measures.

Methods

Participants

Participants were students from four schools that are located in the suburban areas of Taipei City; most families residing in these areas are from middle to high socioeconomic populations. Potential participants were then included only if they met the inclusion criteria: (a) participants must have a BMI of more than 1–2 *SD* above the median (overweight but not obese), based on the World Health Organization Growth Reference (World Health Organization, 2018) for those aged 5–19 years; (b) participants must not have any medical condition that can affect study results or limit PA; and (c) participants must be aged 10–12 years. Exclusion criteria for the study were as follows: (a) participants with comorbid conditions, such as conduct/oppositional defiant disorder, autism spectrum disorders, attention deficit hyperactivity disorder, intelligence, or serious affective disorders; (b) participants with sensory disorders, such as visual imperfections or hearing problems; and

(c) participants with a personal history of brain injury or neurological disorders.

A total of 84 overweight children met the inclusion criteria and were selected. Their mean BMI was $24.84 \pm 3.08 \text{ kg/m}^2$. For the purpose of the study, overweight children were randomly assigned into either the movement intervention condition as the intervention group ($n = 44$) or the control (original PE) condition as the control group ($n = 40$). The overweight children in the intervention group, along with their classmates, participated in the movement games, instead of PE, as a whole class. The overweight children in the control group, along with their classmates, participated in original PE lessons. Pre- and postintervention, participants were asked to complete the Stroop and determination tests. The sample size was estimated using a meta-analysis that reported a small to moderate positive effect of PA on EFs based on randomized controlled trials (i.e., Hedges' $g = .24$ in de Greeff et al. (2018); effect size [ES] $f = 0.25$, $\alpha = .05$, power = .80, groups = 2, measurements = 2, correlation of repeated measurements = .30, $n = 84$). Participants and their parents completed a medical history questionnaire and informed consent form. The study protocol and materials were reviewed and approved by the University of Taipei Institutional Review Board prior to the experiment.

Movement Games Intervention

The intervention was conducted during PE lessons in regular school hours. The frequency of PE classes in the intervention and control groups was 3 days a week for 8 consecutive weeks, and the lessons of PE classes included running games, jump rope games, modified baseball, modified soccer, and modified basketball. Each participant's average heart rate (HR) in both groups during the sessions was recorded during every lesson in both groups, and points were awarded for maintaining an average of >150 beats per minute. Points can be used to redeem weekly prizes in both groups. Weekly prizes were awarded to children who could choose from an assortment of stationeries (valued at approximately US\$ 3).

For the intervention, movement games were designed based on the movement concept and object manipulation skills (Graham, Holt/Hale, & Parker, 2012), and the games that were modified by Davis et al. (2011). Movement concepts and skills focused on the ability to move in various situations, respond to speed, direction and force of movements, and control body movements while jumping, throwing, catching, dribbling, kicking, or passing. During the movement games, PE teachers educated the intervention group's overweight children in a variety of cognition engaging movement skills with comprehension and intensity relevant to the program requirements. With the movement games, the goal in this intervention was to help enhance eye-hand coordination with reaction time and cognitive processing speed. Each lesson began with a 10-min warm-up (moderate cardiovascular activity and static and dynamic stretching), followed by a 30-min movement game. Bouts ended with a water break, slight cool down with cardiovascular activity, and static stretching.

The control (original PE) classes were designed to focus on sport skill development while promoting physical literacy such as motivation, confidence, physical competence, knowledge, and understanding to value and take responsibility for engagement in physical activities for life. The participants learned sport skills to mastery skills to a high level via practice activity. During their practice times, PE teachers demonstrated the sports skills and set up the opportunity for motivating participants to participate in

prescribed activities of sports skills, and then evaluated their performance. Therefore, sport skill acquisition in the control group enabled an individual to be able to move and make tactical decisions efficiently and effectively in game situations. A typical control group lesson lasted 40 min and contained two parts: health fitness activities (10 min) and sport-skill activities (30 min).

Heart rate reserve was used to establish exercise intensity in this study. HR reserve was calculated as maximal HR minus resting HR, where " $206.9 - (0.67 \times \text{age})$ " was an indirect formula for estimating maximal HR (Gellish et al., 2007). During the intervention, the target HR was desired of moderate to vigorous intensity (60–80%), and was calculated by a formula as follows: target HR = (maximal HR – resting HR) $\times$ percentage intensity desired + resting HR. Descriptive data for HR in the exercise manipulation check are presented in Table 1. The overweight children's average HR during the activity (mean of each child's mean values during the intervention period, averaged across children) was 157.93 ± 6.83 beats per minute for the intervention group and 131.56 ± 7.99 beats per minute for the control group, and the intervention group had significantly higher HR than the control group, $t(1, 82) = 16.29$, $p < .0001$, partial $\eta^2 = .77$. Overweight children's average attendance during the intervention was 97.82% ($SD = 4.50$), and there was no significant difference between the movement games ($97.92 \pm 4.26\%$) and original PE classes ($97.71 \pm 4.81\%$), $t(1, 82) = .21$, $p > .05$. [Supplementary Material](https://www.researchgate.net/profile/Chienchih_Chou/research) (available online) of the lessons for movement games associated with this study can also be found at https://www.researchgate.net/profile/Chienchih_Chou/research.

Measures

Stroop test. The Stroop test consists of a color-naming task. The test measures numerous cognitive processes, including inhibition and attention (MacLeod, 1991). Numerous versions of the Stroop test exist; however, in this study, the classic Stroop color-word test was used and consisted of four conditions: baseline condition of reading words, baseline condition of naming colors, incongruent condition of color-word, and incongruent condition of word-color. Each condition consisted of 128 varied stimuli. For the baseline condition of naming colors, stimuli were color names written in the same color of ink (e.g., the word "Blue" written in blue ink and the word "Red" written in red ink). For the baseline condition of reading words, stimuli were color names written in black ink (e.g., the word "Blue" written in black ink and the word "Red" written in black ink). For the incongruent condition of color-word, stimuli were color names printed in a different color ink (e.g., the word "Blue" written in red ink and the word "Red" written in blue ink). For the incongruent condition of word-color, stimuli were reading words that were printed in different color ink (e.g., the word "Yellow" printed in green ink and the word "Green" printed in yellow ink). The interference tendency is calculated using differences between the reaction times of congruent and incongruent conditions. A positive value indicates an increased interference tendency. A negative value is characteristic of a reduced interference tendency. During the test, each participant was instructed to identify the colors of the ink based on the stimuli for each condition as quickly as possible. The stimuli for each condition were displayed on a 15-in. laptop screen, and the participant was asked to press the correct color button on the keyboard for each stimuli of each condition. Participants' performance in Stroop conditions were indexed based on reaction times, which were assessed using a Vienna test system. For the normative sample, split-half

reliabilities varied between $r = .85$ and $r = .99$. The Stroop test was chosen for this study based on past evidence that it is both sensitive to the effects of exercise and provides a reliable measure of EF for overweight children and adolescents (Verdejo-garcía et al., 2010).

Determination test. The determination test was used to provide measurements of discrimination for reaction speed, attention deficits, and reactive stress tolerance in the presence of continuous but rapidly changing acoustic and optical stimuli (Shmygalev et al., 2011). In this study, the main variables were “correct responses and correct responses on time,” which describe the number of accurate (on time and delayed) reactions. Participants’ task was to react as quickly as possible to visual or acoustic stimuli by pressing the corresponding buttons on the response panel. There were five visual stimuli colored in white, yellow, red, green, and blue that were presented in an upper and a lower row. There were two additional visual stimuli in the form of white, rectangular, and visually distinct fields that appeared at the bottom left- and right-hand corners of the screen, which the participant must react to by pressing the corresponding (left or right) foot pedal. Two acoustic stimuli (high and low tone) were assigned to two “sound” buttons in the middle of the panel. The visual stimuli were presented on a 15-in. laptop screen, and the acoustic stimuli were presented through headphones. The next stimulus appeared when the correct responses were entered. The speed of stimulus presentation was self-determined, and the duration of the test was approximately 10 min for each participant. For the test, internal consistencies for the response accuracy rate and correct, on-time responses were between $r = .98$ and $r = .99$.

Fitness. The fitness assessment developed by American College of Sports Medicine (2010) included flexibility (sit and reach test), muscular endurance (sit-ups for 1 min), muscular power (standing long jump), and cardiovascular fitness (a half-mile run in the fastest possible time). Participants were instructed not to engage in intense PA on the day before the evaluations. The four subsets of fitness assessment for participants were converted into standardized T scores, and the physical fitness score was computed as the mean of the scores on these fitness subsets.

Intelligence quotient. The Wechsler Intelligence Scale for Children-IV (WISC-IV) was used in this study as a measure of participants’ IQ. The Chinese version of the WISC-IV is the most popular and widely researched test for children’s intelligence; the test also has good reliability and validity (Yang, Gao, Li, & Zhao, 2015). It incorporates a collection of 13 distinct subtests in two scales: verbal and performance scales. The percentile rank of the WISC-IV was used in this study. The subtest reliabilities are moderate to excellent (.61 to .92). The consistency of IQ subtests and indices for the verbal and performance scales are “very good” to “excellent” (.80 to .97). In this study, the percentile rank was used to convert the subsets of verbal and performance scales.

Data Collection

The experimental procedure consisted of four stages: (a) confirmation, (b) pretest, (c) intervention, and (d) posttest. During the confirmation stage, which took place during the spring semester in 2017, each participant and their parent visited the school and were asked to read and complete the consent form and a medical history questionnaire.

Each participant then entered the pretest stage, during which the Stroop and determination tests were administered. For the Stroop test, each participant was asked to verbally complete the four stages previously described as rapidly as possible by pressing buttons on a keyboard. The participant was then provided with a

5- to 10-min resting period in a quiet classroom before being instructed to verbally perform the determination test according to various color stimuli and acoustic signals presented. Trial errors during the response for the Stroop and determination tests were identified by the examiner, and in case of any error, the participant was asked to repeat the trial until the correct trial was identified.

During the intervention stage, participants in the intervention group were asked to wear sportswear and participate in a children’s movement games program. The gymnastic room wherein the study was conducted had a constant temperature of 25–26 °C and a relative humidity of 65–70%. During each lesson, HR monitors with contact grips were used to measure and record each participant’s HR at 1-min intervals in both the intervention and control groups. Three HR variables were identified, with HR-pre and HR-post representing the HRs assessed before and immediately after each treatment, respectively, and HR-avg representing the average HR noted during the main exercise intervention.

In contrast to the intervention group, participants in the control group participated in PA during PE lessons. During the posttest stage, each participant was asked to complete the Stroop and determination tests within 5–10 min of the end of the treatment. The entire test process lasted 35 min. After the four stages were completed, the participants and their parents were provided with a brief explanation of the study purpose and expectations.

Data Analysis

Group and time were used as independent variables in a two-way mixed randomized controlled trial design. To ensure that any potential confounds were homogenous for the two groups, t test or chi-square test was used to analyze independent samples for continuous or discrete scales of demographic data, respectively. The effects of the movement games on EF were analyzed using the Stroop and determination test scores to conduct another mixed analysis of variance (ANOVA) using a 2 (Group: intervention group vs. control group) $\times$ 2 (Time: pretest vs. posttest) variable approach. For the ANOVAs, simple main effects tests were used to follow-up on any significant interaction effects that were identified, whereas multiple comparisons were used to follow-up on any significant main effects. To control for experiment-wise inflation of α , additional Bonferroni adjustments were made.

Small to moderate ESs were observed for each of the EF domains of interest (0.2 = small ES; 0.5 = moderate ES). ES was calculated according to Cohen’s d (which is equal to the mean difference of the groups divided by the pooled SD), and a partial eta-squared (η^2) for the significant main effects and interactions was reported. The statistical analyses were conducted in SPSS Statistics for Windows (version 19.0; IBM, Armonk, NY), with α equal to .05.

Results

Demographic Analyses

To ensure homogeneity in potential confounds between the control and exercise groups, an analysis of independent samples was applied using t test or chi-square test to compare the demographic data and pretest values of two variables in continuous or discrete scales between groups. The analyses indicated that there were no significant differences between the intervention and control groups in terms of age, height, weight, BMI, fitness, and WISC-IV’s verbal and performance scales, $t(82) = 1.53, -.39, -1.05, -1.56, -.54,$

1.78, and .62, respectively, $p > .05$, thereby suggesting that the two groups were homogenous. Detailed descriptive data are summarized in Table 1.

Inhibitory Control

To evaluate the overweight children's baseline conditions on the inhibitory control, Stroop word (+) and Stroop color (+) tests were performed, and the 2×2 mixed ANOVA revealed no significant Group $\times$ Time interaction, $F(1, 82) = 1.21, 0.03, p > .05$, respectively. Moreover, there were no significant main effects of group, $F(1, 82) = 0.11, 0.01, p > .05$, and time, $F(1, 82) = 1.42, 3.67, p > .05$. The conditions of reading words and naming colors on the baseline conditions are presented in Table 2.

To address the hypothesis of movement games on the incongruent conditions, Stroop word (–) and Stroop color (–), the 2×2

mixed ANOVA revealed significant Group $\times$ Time interactions, $F(1, 82) = 6.86, 9.19, p < .001$, partial $\eta^2 = .11, .10$ with small ES. Follow-up comparisons noted significant time effects in the intervention group, $F(1, 43) = 21.25, 43.72, p < .001$, partial $\eta^2 = .31, .50$ with moderate ES, but not in the control group, $F(1, 39) = 0.11, 4.36, p > .05$. The results show that participants in the intervention group had shorter reaction time in the posttest than in the pretest for the incongruent conditions of reading words and naming colors. Moreover, significant group effects were noted in the posttest, $t(82) = -4.36, -4.19, p < .001, d = 0.49, 0.46$ with moderate ES, thereby revealing that the intervention group exhibited shorter reaction time than the control group in the posttest for both the incongruent conditions of reading words and naming colors.

To address the hypothesis of movement games on the interference tendency, Stroop word ($\pm$) and Stroop color ($\pm$), the 2×2 mixed ANOVA revealed significant Group $\times$ Time interactions,

Table 1 Summary of the Demographic Characteristics of the Participants

Variable	Intervention group	Control group	Total
Gender (M:F)	27:17	25:15	52:32
Age, <i>M</i> (<i>SD</i>)	12.30 (0.66)	12.08 (0.69)	12.19 (0.68)
Grade (fourth:fifth:sixth)	9:12:23	16:11:13	25:23:36
Height (cm), <i>M</i> (<i>SD</i>)	157.63 (6.16)	157.12 (5.70)	157.39 (5.91)
Weight (kg), <i>M</i> (<i>SD</i>)	60.65 (9.74)	62.76 (8.56)	61.66 (9.21)
Body mass index (kg/m ²), <i>M</i> (<i>SD</i>)	24.35 (3.18)	25.39 (2.91)	24.84 (3.08)
Fitness (<i>T</i> score), <i>M</i> (<i>SD</i>)	49.68 (6.29)	50.37 (5.48)	49.99 (5.89)
WISC-IV (PR), <i>M</i> (<i>SD</i>)			
Verbal scale (PR)	70.91 (23.37)	61.90 (22.90)	66.21 (23.44)
Performance scale (PR)	63.39 (28.32)	59.85 (23.67)	61.70 (26.11)
HR for exercise manipulation check, bpm (<i>SD</i>)			
HR-pre	73.75 (2.69)	73.40 (1.63)	–
HR-avg	157.93 (6.83)	131.56 (7.99)	–
HR-post	105.46 (3.69)	110.30 (5.33)	–
Average attendance, % (<i>SD</i>)	97.92 (4.26)	97.71 (4.81)	97.82 (4.50)

Note. Fitness test and WISC-IV were conducted at the beginning of the study. PR = percentile rank; HR = heart rate; WISC-IV = Wechsler Intelligence Scale for Children-IV; bpm = beats per minute; M = male; F = female.

Table 2 Descriptive Statistics and ESs of an 8-Week Movement Games on the Stroop and Determination Tests

Variable	Intervention group			Control group		
	Pretest <i>M</i> (<i>SD</i>)	Posttest <i>M</i> (<i>SD</i>)	ES	Pretest <i>M</i> (<i>SD</i>)	Posttest <i>M</i> (<i>SD</i>)	ES
Stroop test (s)						
Reaction time						
Stroop word (+)	0.68 (0.08)	0.68 (0.09)	0.00	0.69 (0.06)	0.67 (0.12)	0.14
Stroop color (+)	0.69 (0.09)	0.67 (0.09)	0.23	0.69 (0.06)	0.67 (0.05)	0.26
Stroop word (–)	0.96 (0.22)	0.85 (0.15)	0.76	1.02 (0.16)	1.01 (0.17)	0.06
Stroop color (–)	0.89 (0.15)	0.77 (0.12)	0.83	0.92 (0.14)	0.87 (0.08)	0.36
Stroop word–color ($\pm$)	0.28 (0.20)	0.17 (0.13)	0.79	0.32 (0.17)	0.33 (0.19)	0.04
Stroop color–word ($\pm$)	0.22 (0.11)	0.10 (0.14)	0.64	0.22 (0.14)	0.19 (0.08)	0.21
Determination test						
Response accuracy rate (%)	87.45 (5.46)	94.43 (1.13)	1.28	88.79 (4.58)	90.27 (4.10)	0.29
Correct responses on time (s)	0.80 (0.08)	0.70 (0.07)	1.43	0.83 (0.08)	0.81 (0.09)	0.22

Note. EFs is calculated by Cohen's *d*. ES = effect size; (+) = baseline condition; (–) = incongruent condition; ($\pm$) = interference tendency.

$F(1, 82) = 3.90, 19.96, p < .01$, partial $\eta^2 = .05, .19$ with small ES. Follow-up comparisons noted significant time effects in the intervention group, $F(1, 43) = 22.43, 25.19, p < .001$, partial $\eta^2 = .34, .37$ with moderate ES, but not in the control group, $F(1, 39) = 0.29, 1.45, p > .05$. The results show that participants in the intervention group had smaller interference tendencies in the posttest than in the pretest for the conditions of reading words and naming colors. Likewise, significant group effects were noted in the posttest, $t(82) = -4.49, -4.72, p < .01, d = 0.52, 0.57$ with moderate ES, thereby indicating that the intervention group exhibited smaller shorter interference tendencies than the control group in the posttest for both the conditions of reading words and naming colors.

Attention Function

To address the hypothesis of movement games on the response accuracy rate, the 2×2 mixed ANOVA revealed a significant Group $\times$ Time interaction, $F(1, 84) = 22.25, p < .001$, partial $\eta^2 = .21$ with small ES. Follow-up analyses noted a significant time effect in the intervention group, $F(1, 43) = 71.45, p < .001$, partial $\eta^2 = .62$ with moderate ES, whereas no change was noted in the control group, $F(1, 39) = 3.24, p > .05$. The result shows that the intervention group had a higher response accuracy rate in the posttest than in the pretest. Likewise, significant group effects were noted in the posttest, $t(82) = 6.48, p < .001, d = 0.48$ with moderate ES, thereby indicating that the intervention group exhibited a higher accuracy rate than the control group in the posttest for the determination test.

To address the hypothesis of movement games on the correct on time, the 2×2 mixed-design ANOVA revealed significant Group $\times$ Time interactions, $F(1, 84) = 19.14, p < .001$, partial $\eta^2 = .19$ with small ES. Further comparisons noted a significant time effect in the intervention group, $F(1, 43) = 88.94, p < .001$, partial $\eta^2 = .67$ with moderate ES, but not in the control group, $F(1, 39) = 1.67, p > .05$. The results show that participants in the intervention group had shorter correct, on-time responses in the posttest than in the pretest for the determination test. Moreover, a significant group effect was noted in the posttest, $t(82) = -6.04, p < .001, d = 0.84$ with moderate to high ES, thereby revealing that the intervention group showed shorter correct, on-time responses than the control group in the posttest for the determination test.

Discussion

The main purpose of this study was to explore the effects of an 8-week movement games intervention on EFs among overweight children. The results of this study support the hypothesis that overweight children's EF indices of inhibitory control and attention function were significantly improved by the movement games. To summarize, these results are consistent with studies on general children populations regarding the demonstrable changes in behavioral inhibition and attentional ability caused by PA (Best, 2010; Gomez-Pinilla & Hillman, 2013). For inhibitory control, the intervention group showed significantly reduced response time in incongruent conditions and interference tendency after the intervention, whereas no significant difference was noted for the control group in incongruent conditions and interference tendency. For attentional function, the intervention group demonstrated a higher response accuracy rate and significantly shortened correct, on-time responses than the control group. Because overweight children in both groups have the same baseline in terms of IQ and fitness level and showed no differences in response time in the pretest, these

findings can be attributed to various interventions they received during the study. However, although movement games were noted to be similar by using an HR monitor, HRs during intervention were significantly higher in the intervention group, compared with the control group, thereby indicating that the intensity and content of movement game activities can be another potential attribute that contributes to the enhanced EF performance that was identified in the current study. Based on the study findings, movement games are suggested to further improve the EF of overweight children in PE.

Throughout childhood, the development of EF by using PA is crucial for adaptive behavior in overweight children (Crova et al., 2014; Davis et al., 2011). In particular, overweight children's capacity for inhibiting inappropriate responses is crucial for their academic performance and social and emotional well-being in elementary school (Crova et al., 2014; Davis et al., 2011; Yang et al., 2018). The study findings may have crucial implications for developing behavioral inhibition in overweight children. Studies have noted a relationship between PA and behavioral inhibition among overweight children (Davis et al., 2007, 2011; Song et al., 2016). Studies have also provided supporting evidence regarding the positive effect of physical exercise on the inhibition of a dominant response by using the Stroop test for healthy (Telles, Singh, Bhardwaj, Kumar, & Balkrishna, 2013) and overweight children (Davis et al., 2011). Krishnakumar and Geeta (2006) noted that an acute 30-min bout of moderate-intensity aerobic exercise improved the Stroop color-word condition in overweight children, and suggested that physical exercise of this type was beneficial for inhibition. Huang et al. (2015) assessed the effects of physical exercise over a 6-week period, and noted that the overweight children training group had significantly improved scores in the Stroop color-word condition. These findings regarding the Stroop test were comparable with that of the current study, which illustrates the positive effect of movement games, regardless of the type of manipulate motor skills, as a critical component of the Stroop color-word performance. Although the mechanism of such a relationship is not yet fully understood in the present study, the benefits of movement games on inhibitory control are acknowledged and may result in the enhancement of an individual's concentration and cognitive inhibition. However, extended follow-up studies are required to determine whether the benefits of movement activity are transient and only persist during the movement games.

The results of this test were consistent with our hypothesis because the EG illustrated improved performance in the Stroop color-word and word-color conditions after the movement games. In particular, selective attention for the color-word or word-color conditions is measured using the Stroop test, which requires the participant's completion of a required unusual task to measure cognitive inhibition or inhibition of a dominant response (Chang et al., 2012; Miyake et al., 2000; Schwartz & Verhaeghen, 2008). The EG group only showed a marginal increase in performance in the Stroop color-word condition, compared with the other tests. Because basic reading and naming rate and motor speed ability were measured in both the congruent and incongruent conditions, this may reflect the ability to inhibit the overlearned response during the conflicting stimulus, which is believed to confer with the inhibition or interference of EF (Homack & Riccio, 2004). Therefore, these results suggest that inhibition-related EF benefited from movement games in overweight children.

Our findings, determination improvement in the intervention group but not in the control group, extend previous findings

regarding the beneficial effect of a physical exercise intervention on attention function (Nederhof, Lemmink, Zwerver, & Mulder, 2007; Telles et al., 2013). The results show that our movement games intervention had a beneficial effect on the concentration aspect of overweight children. The use of a randomized controlled trial design further establishes the causal nature of the intervention for this effect. The movement games intervention enhanced the response accuracy rate and correct, on-time responses of the determination test. The determination test in EFs involved both distinguishing and identifying multiple stimuli reactions, which provides an understanding of reactive stress tolerance, attention deficits, and reaction speed in the presence of rapidly changing and continuous stimuli (Shmygalev et al., 2011). Stimuli reaction includes the response accuracy rate and correct, on-time responses, which represents the ability to attend to the correct response set and is associated with EF and determination ability. Response accuracy rate and correct, on-time responses reflect the participants' efficiency in identifying the correct dimension and the ability to continuously respond accurately, which is related to attention. Our findings suggest that the improved attention function that is attributed to the movement games intervention may depend on EF.

The movement games led to increases in response accuracy rate and decreases in correct, on-time responses, thereby indicating that the increased intervention sustained continuous, rapid, and varying responses to rapidly changing stimuli in overweight children; however, group-specific differences were observed in both variables. Although the effect of movement games on attention remains arguable, the observation of an increased response accuracy rate and decreased correct, on-time responses after the physical exercise program is analogous to the findings of studies that employed a cross-sectional comparison or training protocol (Chang et al., 2012; Nederhof et al., 2007; Telles et al., 2013). The improved determination condition has been suggested as the primary indicator of positive PA adaptation (Chang et al., 2012). The increase in HR during the movement games intervention may be particularly crucial for overweight children, who typically demonstrate good inhibitory control skills to resist the impulsiveness to manipulate motor skills (Kubesch et al., 2009).

Another novelty of the current study is that it explored the potential mechanism underlying the relationship between movement games and attention function by using moderate- to vigorous-intensity HR. In addition to our observation regarding improved HR after the movement games, our findings revealed an increase in the response accuracy rate and a decrease in correct, on-time responses during moderate- to vigorous-intensity HR. For this finding, the evidence supports the possibility of an autonomic link between movement games and EF. The significantly positive effects shown in the determination test were identified for response accuracy rate and correct, on-time responses. They were consistent with the idea that the alteration of complex psychomotor activity caused by the movement games intervention would affect the attention aspect of EF. The study findings align with those of Chang et al. (2012), who noted that moderate-intensity physical movement improved the determination condition in overweight children. However, these findings differ from that of recent studies by Davis et al. (2011) and Song et al. (2016). The conditions under which movement games with moderate- to vigorous-intensity HR were assessed may have contributed to these differences. Song et al. (2016) assessed movement games with moderate to vigorous intensity during an EF task instead of assessing it during the PA state, as we did in the current study.

Limitations and Future Research

This study had some limitations that warrant caution with the interpretation of its results and future research. First, future studies should consider the open- and closed-motor skills of the designed program to deduce further conclusions regarding how different characteristics in motor skills affect overweight children's performance on EF. Second, future research regarding the relationship between movement games and EF should consider multiple factors that may be emphasized in overweight children. Factors such as adequate sleep, good nutrition, struggles with physical or mental health, and additional practice (movement games, video games, etc.) have been shown to influence neurocognitive performance in obese individuals (Davis et al., 2011; Song et al., 2016). Third, although the study aimed to examine inhibitory control and attention function, the findings were unable to draw conclusions about other aspects of EF, such as updating, shifting, and planning. Further examination of these specific aspects may offer an improved understanding. Fourth, a limitation common to behavioral trials in school PE settings was that children were not blinded to their group assignment, including the motivation of prizes, nor were interventionists blind to the conditions or the hypothesis of the study. Nonetheless, evaluators were blinded to group assignment to obtain an unbiased assessment of cognitive outcomes.

Conclusion

The current study indicates the causative influence of teaching movement games on the inhibitory control and attention aspects of EF in overweight children. The findings also suggest that comprehension, enjoyableness, and intensity with manipulate skills following participation in PE may be associated with the effects of movement games on EF, thereby providing preliminary evidence for a relationship between movement games and EF from the perspective of moderate to vigorous intensity by using an HR monitor. Based on the beneficial effects of the movement games program on EF in overweight children, schools should consider maximizing opportunities to engage overweight children in moderate- to vigorous-intensity movement game activities while teaching PE.

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