EXERGAMING ENHANCES CHILDREN’S EFFICIENCY TO RESOLVE VISUOSPATIAL INTERFERENCE

by

JOHN R. BEST

(Under the Direction of Patricia H. Miller)

ABSTRACT

The current study examined as important aspect of experience—physical activity—that may contribute to children’s executive function. The design attempted to tease apart two important aspects of children’s exercise by examining the separate and combined effects of acute physical activity and cognitive engagement on an aspect of children’s executive functioning. In a 2 X 2 within-subjects experimental design, children (N = 33, aged 6-10) completed activities that varied systematically in both physical activity (physically active video games versus sedentary video activities) and cognitive engagement (challenging and interactive video games versus repetitive video activities). Cognitive functioning, including executive function, was assessed after each activity by a modified flanker task. Whereas cognitive engagement had no effect on any aspect of task performance, physical activity (i.e., exergaming) enhanced children’s speed to resolve interference from conflicting visuospatial stimuli. The results extend past research by showing more precisely how physical activity influences executive function while demonstrating that interactive video gaming can be an effective experimental tool.

INDEX WORDS: Executive function, physical activity, exergaming, cognitive engagement
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by

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CHAPTER 1
INTRODUCTION

Interacting with the environment in accordance to a desired goal while concomitantly not interacting in a more automatic, yet undesirable manner is an ability that most healthy adults take for granted. This ability results in goal-directed and controlled behavior and is made possible by a set of cognitive processes often referred to as executive function (EF; e.g., Banich, 2009). Because EF allows the individual to override an automatic response to respond more strategically or flexibly, it requires a high level of effort, meaning that it is costly in terms of energy consumption (Suchy, 2009). As such, EF is optimal when the individual has a sufficient pool of attentional resources that can be allocated to the task at hand.

Developmental researchers have an interest in EF because children often have a difficult time successfully engaging EF to act in a controlled, goal-directed fashion. In fact, EF follows a protracted period of development and does not reach full maturation until early adulthood (see Best, Miller, & Jones, 2009 for a review). However, for children, as for adults, there are numerous situations in which EF is needed. As examples, EF is needed to pay attention in class, ignore distractions, self-direct learning, and self-regulate emotions (Blair & Diamond, 2008). It is no surprise that children with better performing EF have an easier transition from preschool to formal schooling (Blair & Diamond, 2008), behave more appropriately in the classroom (Riggs, Blair, & Greenberg, 2003), and show higher achievement in a number of academic domains (Müller, Lieberman, Frye, & Zelazo, 2008). EF’s importance to children’s functioning have prompted investigations of ways in which EF can be enhanced during development and include
examinations of child-centered learning (Diamond, Barnett, Thomas, & Munro, 2007), adaptive computerized training (Rueda, Rothbart, McCandliss, Saccamanno, & Posner, 2005; Thorell, Lindqvist, Nutley, Bohlin, & Klingberg, 2009), and mother-child interactions during planning (Perez & Gauvain, 2009), among others.

Effects of Acute Physical Activity on Children’s Executive Function

Although it has been largely overlooked by developmental researchers, physical activity (PA) may be one way to immediately enhance children’s EF. Recent experimental studies demonstrate that single bouts of PA (i.e., acute PA) selectively benefit EF and have smaller, often non-significant effects on non-EF processes (see Best, in press and Tomporowski, 2003 for reviews). Research has posited two main underlying mechanisms. Firstly, PA is thought to increase the participant’s level of arousal, representing a larger pool of available attentional resources, which in turn facilitates performance on tasks that require significant effort such as EF-intensive tasks (Audiffren, 2009). This mechanism refers to physiological arousal and is supported by studies showing that single bouts of repetitive PA (e.g., stationary cycling or treadmill walking) facilitate EF relative to rest periods of equivalent length (Ellemberg & St. Louis-Deschênes, 2010; Hillman, Pontifex, Raine, Castelli, Hall, & Kramer, 2009). Secondly, PA may engage certain higher-order cognitive processes and prime them for subsequent use. This mechanism, which is less established in the literature, refers to cognitive engagement (CE) and is supported by studies showing that more cognitively-engaging PA (i.e., PA that engages higher-order cognitive processes by requiring adaptive play in a challenging context, such as group games or bilateral coordinative exercises) enhances cognitive functioning, including EF, to a greater degree than non-engaging (i.e., repetitive and non-adaptive) PA of equivalent intensity and length (Budde, Voelcker-Rehage, Pietrabyk-Kendziorra, Ribeiro, & Tidow, 2008; Pesce,
Crova, Cereatti, Casella, & Bellucci, 2009). Ostensibly, both cognitively-engaging and non-engaging PA induce a state of physiological arousal, but only the former activates specific higher-order cognitive processes and primes them for subsequent use (Pesce et al., 2009).

That the combination of PA and CE has a particularly robust effect on children’s EF is intriguing; however, a few prominent issues weaken conclusions drawn at this time. Most importantly, in comparing team-based PA to individual-based repetitive PA, CE and social interaction are confounded. Social interaction has been linked to children’s EF development (Carlson, 2009), and therefore, it is plausible that team games enhance subsequent EF because they are social in nature rather than (or perhaps in addition to) being complex and challenging. Secondly, it is uncertain whether it is the combination of PA and CE that impacts EF or whether CE in the absence of PA similarly impacts EF. There is some evidence that regular CE in the form of sedentary, computerized training transfers to novel EF task performance in children (e.g., Thorell et al., 2009), but the effectiveness of a single training session has not been determined. The current study had children participate in activities that varied systematically in both PA and CE, and importantly, the activities were completed individually to control for the effects of social interaction. This allowed for a precise determination of the separate and combined effects of PA and CE on subsequent EF performance.

*Exergaming as Physical Activity*

Because of their growing popularity and sophistication of their interface with the player, it is important to consider exergames as a possible way to engage children in PA (Staiano & Calvert, in press). Exergames (a portmanteau of “exercise” and “games”) are a new generation of video games that stimulate a more active, whole-body gaming experience. Empirical research with exergames is limited, but the few extant studies report the potential of exergames to
promote PA (Graves, Stratton, Ridgers, & Cable, 2007). Exergames have several other attributes that make them ideal for experimental research with children. Exergames are relatively inexpensive, are widely available, require a small amount of space, and can be played alone or with others (Papastergiou, 2009). Importantly, by increasing the complexity of certain aspects of the game (e.g., game rules, speed and coordination of responses) these games can be designed to require constant CE from the player in order to play successfully. This need for CE could prime higher-order cognitive processes for subsequent tasks; however, so far no research has used exergames to vary the need for CE during PA to determine the separate and combined effect of PA and CE on subsequent cognitive functioning.

The ex-Gaussian Approach to Response Time Data

Another contribution of the present study is to identify more specifically how performance on an EF task is affected by PA and CE. Typically, a cognitive assessment contains numerous trials (e.g., 50 to 100), from which the researcher computes a summary measure (or measures) of performance. In addition to participants’ accuracy (e.g., whether a specific task trial was completed correctly or not), participants’ response time (RT)—i.e., the time taken to complete each trial—provides an indication of the performance of the cognitive process(es) under study. As is commonly done, RT can be summarized as a single measure by determining the central tendency (i.e., mean, median) of RTs across all trials; statistical tests then can compare differences in this summary measure across experimental conditions to determine their effects on cognition. There are several potential disadvantages of this approach. Foremost, the distribution of a participant’s RT across the numerous trials of a task typically is non-normal—that is, it rises sharply on the left side (fast response times) and falls off slowly on the right (slow response times), producing a long skewed tail. Many of the responses located in the skewed tail
may represent outliers, which are responses generated by processes that are not meant to be assessed by the cognitive task, such as lapses in attention (Ratcliff, 1993; Unsworth, Redick, Lakey, & Young, 2010). In addition to representing processes that may not be of interest to the researcher, outliers can reduce the power of statistical tests when measures of central tendency are used without transforming the data and/or removing extreme response times (Bush, Hess, & Wolford, 1993; Wilcox, 1998). Thus, the results of a statistical test may indicate a null effect on cognition, when in fact there truly is an effect. Furthermore, measures of central tendency provide limited information about the shape of the RT distribution and how the experimental conditions may affect it (McAuley, Yap, Christ, & White, 2006; Spieler, Balota, & Faust, 2000).

One manner to address these issues is to fit an ex-Gaussian distribution to the RT data, which provides parameters that describe the entire RT distribution (Heathcote, Popiel, & Mewhort, 1991; Ratcliff, 1993). Figure 1 provides a graphical depiction of the ex-Gaussian approach to RT data analysis. The ex-Gaussian distribution is the convolution of a Gaussian (i.e., normal) distribution and an exponential distribution. In fitting an ex-Gaussian distribution to the empirical data, three parameters are estimated: Mu ($\mu$) and sigma ($\sigma$) represent the mean and standard deviation, respectively, of the normal portion of the distribution (i.e., the left hump). Given that the distribution rises rapidly on the left, $\mu$ and $\sigma$ characterize the leading edge of the RT distribution (Davranche, Audiffren, & Denjean, 2006; Matzke & Wagenmakers, 2009). The third parameter, tau ($\tau$), represents the mean and standard deviation of the exponential portion of the distribution (i.e., the right tail), which is formed from unusually slow responses. As noted above, such responses often occur during lapses of attention to the task, for example when distracted by external stimuli (e.g., someone’s voice coming from an adjacent room) or internal thoughts (e.g., thinking about what you will eat for dinner) (Unsworth et al.,
Thus, in addition to providing a manner to more accurately capture the form of the RT distribution, an ex-Gaussian analysis provides parameters (i.e., \( \mu \) and \( \sigma \)) that characterize the performance of the cognitive processes of interest when attention is focused on the task and a parameter (\( \tau \)) that characterizes unusually slow responses that may result from lapses in attention.

The three ex-Gaussian parameters can be related to the mean and variance of the entire distribution in the following way:

\[
M = \mu + \tau \]

\[
SD^2 = \mu^2 + \sigma^2
\]

In light of these equations and the current study, if PA (or CE) reduces the overall mean RT, it could signify two distinct effects. For example, a reduction in \( \mu \) signifies a shift in the normal component of the RT distribution. This would indicate that PA, relative to sedentary activity, enhances the speed of the most frequent and fastest responses on the task; that is, the participant’s fastest trial responses are faster when preceded by PA than when preceded by sedentary activity. This would provide strong evidence that PA actually enhances the efficiency of the cognitive processes tapped by the task (e.g., executive processes needed to respond selectively in the presence of interference). Alternatively, a reduction in \( \tau \) signifies a decrease in unusually slow responses, which would suggest that PA increases the participant’s sustained attention across the task session, resulting in fewer lapses in attention. Thus, the ex-Gaussian approach can provide a more detailed understanding of how PA affects cognitive function that cannot be revealed by looking at measures of central tendency alone.
Current Study

The current study addresses the aforementioned issues using a 2(PA: high, low) X 2(CE: high, low) within-subjects experimental design. Children completed different activities during separate experimental sessions that varied systematically in PA (exergames requiring whole-body vigorous movement versus sedentary activities) and in CE (games requiring challenging, adaptive play versus activities requiring repetitive actions). This design ensured a high level of control across the experimental sessions and across children. It also allowed children to complete each condition individually, avoiding the confounding of individual versus group activity with variables of interest. Children’s cognitive functioning was assessed after each experimental activity using a modified flanker task, the Child Attention Network Test (ANT-C) (Rueda, Fan, McCandliss, Halparin, Gruber, Lercari, et al., 2004). This task contains trials that require EF to resolve interference (incongruent trials) and trials that do not (congruent trials); EF can be assessed selectively by subtracting congruent trial performance from incongruent trial performance. Both response accuracy and RT were used to determine children’s performance on the task; to measure RT, the overall mean and standard deviation, as well as the three ex-Gaussian parameters (i.e., $\mu$, $\sigma$, $\tau$), were utilized, in order to identify the specific aspects of improvement. Children between the ages of 6 and 10 were chosen for participation because it is known that EF performance continues to improve across this age range (Best et al., 2009), and interference control, as measured by the ANT-C, improves until at least age 8 (Rueda et al., 2004). Thus, this task should be effortful for the participants, and task performance should be sensitive to their ability to allocate energetic resources to the task. By using a 2X2 design, the current study determined whether PA and CE, both separately and combined, enhances children’s ability to resolve interference to make a goal-directed response.
CHAPTER 2

METHODS

Participants

Thirty-three children (20 boys and 13 girls) between the ages of 6 and 10 completed the study. Twenty-two children were recruited from an afterschool program in a local elementary school, and 11 children were recruited from the local community to complete the study in a University laboratory. Research flyers were the primary means of recruitment. All participants provided written assent and their legal guardians provided written informed consent in accordance with the Institutional Review Board. Data for one additional child, who provided written assent but completed only one session, were not analyzed. Prior to testing, legal guardians reported their child’s date of birth, gender, handedness, height, weight, race and parental education level. Additionally, legal guardians reported that their child had normal or corrected-to-normal vision, had never been diagnosed with an attentional disorder or other neurological disorder, was not taking medications that may interfere with research measurements (e.g., antipsychotics, stimulants, sedating antihistamines), had no hearing problems, and had no condition preventing the child from safely participating in vigorous PA. At the end of the first session, children were asked how often they participated in PA and how much time they spent playing video games on weekdays and weekends. Table 1 provides the demographic, PA, and video game playing data. Additionally, the parental reports indicated that for all participants at least one parent had completed a college degree and that at least one parent reported their race as
“White/Caucasian.” The two samples were similar; there were no significant differences in any of these variables across the two samples of children ($p > .10$).

**General Procedure**

A within-subjects design had children participate in four separate experimental sessions. Children completed each session individually and were tested during an afterschool program in an unused, quiet classroom ($n = 22$) or in a laboratory on the university campus ($n = 11$). Each session was approximately 1 hour long, occurred at approximately the same time of day, and was separated from the previous session by an average of 9 days ($M = 9.3$, $SD = 4.7$). Children were asked to maintain a similar level of PA during the day before the session on all testing days. At the beginning of every session, the child was fitted with heart rate monitoring equipment and familiarized with a perceived exertion scale. Next, the child received one of the four experimental activities (see detailed description below), with specific instructions for how to complete the activity. For children completing the study in the afterschool program, the activities were displayed on a SMART Board 600 interactive whiteboard (154.94 cm X 116.84 cm). For children completing the study in the laboratory, the activities were displayed on a Sharp Aquos LCD HDTV (126.49 cm X 86.87 cm). In each testing environment, the child was positioned approximately 1.8 m away from the screen. The order of the activities was counterbalanced across children to distribute the experimental activities across the four sessions and to ensure that the order was not confounded with either age or gender. That is, each condition occurred approximately equally often in the first, second, third, or fourth position within each gender and for younger and older children (based on median split). Each activity lasted approximately 23 minutes, including a water break at the halfway point. After completing the activity, the heart rate monitoring equipment was removed, the child was given a break of
approximately 2 minutes to drink water and choose a small prize from a prize box, and was escorted to the computer station to complete the cognitive assessment. Finally, the child completed a questionnaire to assess the child’s engagement in the specific activity of that session. At the very end of the fourth session, the child received a certificate recognizing his or her completion of the study.

**Low CE, low PA (Video).** The child sat comfortably and watched an age-appropriate video on healthy living habits (*Human Body for Children: All about Nutrition & Exercise*; Schlessinger Science Library, 2001). Before beginning the video, the child was asked to sit still and to remain awake during the entirety of the video. At the halfway point (10 minutes into the video), the video was paused to allow for a water break and then continued for another 10 minutes.

**High CE, low PA (Mario).** The child sat comfortably and played a sedentary video game using a handheld controller on a Nintendo Wii (*Super Mario World*; Nintendo, Redland, WA). This game is a platform game, in which the child moves his/her character across the screen from left to right. The child used the controller buttons to jump over obstacles, duck to avoid obstacles, and to collect items (e.g., turtle shells) for use against opponents. As the child progressed through the game, it became more difficult (e.g., presence of stronger and/or more opponents). The child was asked to sit still while playing the game. After playing for approximately 10 minutes, the game was stopped to allow for a water break. The child then played the game a second time for approximately 10 minutes.

**Low CE, high PA (Marathon).** The child played an exergame entitled “Marathon” included in *Active Life: Outdoor Challenge* (Namco Bandai, Santa Clara, CA) for the Nintendo Wii, in which the child's virtual character is challenged to run as far as possible in 10 minutes.
The child’s responses were recorded via pressure-sensitive buttons on a response mat (91.44 cm X 82.55 cm) that connects to the Nintendo Wii. To play this game, the child moved the character forward, down a straight corridor, by jogging in place on the response mat. The child was asked to maintain a steady pace, and a speedometer in the lower right corner of the screen displayed the character’s virtual speed. This exergame was a repetitive PA similar to jogging on a treadmill. At the conclusion of the 10-minute game, the child was given a brief break to drink water. The child then completed a second, identical bout of the game.

High CE, high PA (Mini-Exergames). The child played an exergame entitled “Mini-Exergames”, also included in Active Life: Outdoor Challenge. This exergame used the same response pad used in the Marathon condition and consisted of several mini-games. Depending on the mini-game, the child jogged in place to move the character, moved from side to side to move the character horizontally on the screen, and jumped to avoid pits, rolling logs, or other obstacles. Each mini-game became more difficult (e.g., obstacles approached more randomly and/or more unpredictably) as the child progressed. Thus, it required adaptive play similar to that required in Mario and high PA like in Marathon. Each mini-game took 2 minutes to complete and was followed by a very brief (10 second) break before the next mini-game began. The child completed 5 mini-games, lasting approximately 10 minutes, then was given a water break at the completion of the 5th game. The child then completed a second, identical bout of the mini-games.

Heart Rate Monitoring and Perceived Exertion during Activity

The child’s heart rate (HR) data were collected during each experimental activity using a HR monitor and strap (Polar S810i HR monitor; Polar Electro, Oy, Finland). The HR strap fitted snugly around the child’s chest and transmitted data to a monitor worn on the child’s preferred
wrist. The child also reported his/her perceived exertion, using the OMNI procedure (Utter, Robertson, Nieman, & Kang, 2002), at the beginning, middle, and end of each experimental activity. The OMNI was created specifically for children and assessed rating of perceived exertion (RPE) from zero ("not tired at all") to ten ("very, very tired") using a pictorial scale. The child was instructed that “tired” did not refer to “drowsiness” or “sleepiness” but to “muscle fatigue” and “physical exertion.”

*Behavioral Assessment and Children’s Self-Report of Activity Engagement*

The child’s engagement in each experimental activity was quantified using an observational checklist completed by a research assistant. It contained two items: “How many times does the child express enjoyment during the activity? (Examples: saying ‘Yes!’ ‘Great!’ ‘I did it!’)” and “How many times does the child express frustration during the activity? (Examples: saying ‘This is hard!’ ‘Shoot!’).” Research assistants were trained on the videos from pilot testing and completed a checklist for a test video. Inter-rater reliability for this test video was acceptable, intraclass \( r = 0.81 \).

At the end of each session, after completing the cognitive assessment, the child completed an 8-item questionnaire that also assessed the child's engagement in the specific experimental activity. It contained 5 items that asked the child to compare the activity they just participated in to other common activities (e.g., “Which would you rather do, play this video game on the Wii or play your favorite game on the playground?”). It also contained 3 statements to which the child was asked to respond “Yes” or “No” (e.g., “I really felt like a character in the game”). Scores ranged from 0 (preferred all 5 alternative activities to the experimental activity and answered “No” to all 3 statements) to 8 (preferred the experimental activity to all 5
alternatives and answered “Yes” to all 3 statements). This questionnaire had an average reliability (Cronbach’s $\alpha$) of 0.62.

Cognitive Assessment

The ANT-C is a computerized adaptation of the flanker task that uses cartoon fish rather than arrows (Rueda et al., 2004). The child sat at a desk in front of a laptop computer (Dell Inspiron 6000, 33.02 cm X 20.96 cm LCD Screen) at a distance of approximately 50.80 cm from the screen to the child’s head. Responses were recorded using a computer mouse built into the laptop keyboard. Each trial began with a central fixation cross with a random duration of between 400 and 1600 ms. Next a target array appeared consisting of a yellow colored line drawing of either a single fish or a horizontal row of five yellow fish. The child was asked to respond with either a left or right button press, using the pointer finger from either the left or right hand respectively, based on whether the central fish was pointing to the left or right. Flanker trials (either congruent or incongruent at random) occurred on 67% of trials. On congruent trials, the flanking fish faced the same direction as the central fish; on incongruent trials, the flanking fish faced the opposite direction as the central fish. The target array appeared and remained on the screen until the child made a response, to a maximum of 1700 ms. If the child did not make a response within 1700 ms, the computer recorded the child as making an omission error and the next trial began. If the child made a correct response, a pre-recorded voice exclaimed, "Woo-hoo!" If the child made an incorrect response, a buzzer sounded briefly. The child completed a set of 12 practice trials and 2 blocks of 48 test trials each. The child was given encouragement during the practice trials to respond as quickly and accurately as possible (e.g., "Remember, you should feed only the middle fish."). No encouragement or correction was given during the testing blocks. The child was allowed a brief break between the two testing
blocks in order to pick out a hard candy (to be consumed after the experimental session) and to drink water. The entire task required approximately 12 minutes.

Statistical Analysis

Before examining the effects of the experimental manipulation on children’s ANT-C performance, preliminary analyses examined differences across the experimental activities in CE (both observed and reported), average HR, and RPE. These analyses provided manipulation checks of the PA and CE aspects of each condition. To perform these analyses, the four experimental conditions were grouped into low and high categories of PA and CE, and then separate 2 X 2 mixed-model ANOVAs tested the main effects of PA and CE, and their interaction (PA X CE), on these manipulation check variables. For the main analyses, the same statistical model (2 X 2 mixed-model ANOVA) analyzed ANT-C performance. The ANT-C performance measures of interest were each child’s RT on correct trials and accuracy (percent correct) for each flanker type. Regarding RT, four separate measures were used: the overall mean of the RT distribution and the three ex-Gaussian parameters (i.e., μ, σ, τ). The ex-Gaussian parameters were estimated using the statistical package Quantile Maximum Probability Estimator (QMPE v2.18; Brown & Heathcote, 2003; Heathcote et al., 2004). Using the parameters estimated in QMPE, these analyses were conducted using Statistical Package for the Social Sciences (SPSS v17.0). To increase the sensitivity of the analyses, position effects (i.e., improvements on the ANT-C that occurred with repeated exposure) were removed from the error variance by creating a Latin square residual (Keppel, 1991). Partial eta-squared (ηp²) provided a measure of effect size for statistically significant results.
Table 1

*Means, Standard Deviations, and Percentages for Demographic Information*

<table>
<thead>
<tr>
<th>Demographic Variable</th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (years)</strong></td>
<td>8.1 (1.3)</td>
</tr>
<tr>
<td>6 years (n = 8)</td>
<td></td>
</tr>
<tr>
<td>7 years (n = 7)</td>
<td></td>
</tr>
<tr>
<td>8 years (n = 8)</td>
<td></td>
</tr>
<tr>
<td>9 years (n = 10)</td>
<td></td>
</tr>
<tr>
<td><strong>Body Mass Index (kg/m²)</strong></td>
<td>17 (3)</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
</tr>
<tr>
<td><em>Male</em></td>
<td>61%</td>
</tr>
<tr>
<td><em>Female</em></td>
<td>39%</td>
</tr>
<tr>
<td><strong>Handedness</strong></td>
<td></td>
</tr>
<tr>
<td><em>Right</em></td>
<td>84%</td>
</tr>
<tr>
<td><em>Left</em></td>
<td>15%</td>
</tr>
<tr>
<td><strong>Regularly active?</strong></td>
<td></td>
</tr>
<tr>
<td><em>Yes</em></td>
<td>91%</td>
</tr>
<tr>
<td><em>No</em></td>
<td>9%</td>
</tr>
<tr>
<td><strong>Typical weekday video game playing (per day)</strong></td>
<td></td>
</tr>
<tr>
<td><em>Never</em></td>
<td>33%</td>
</tr>
<tr>
<td><em>30 minutes</em></td>
<td>45%</td>
</tr>
<tr>
<td><em>1 hour</em></td>
<td>15%</td>
</tr>
<tr>
<td><em>More than 1 hour</em></td>
<td>6%</td>
</tr>
<tr>
<td><strong>Typical weekend video game playing (per day)</strong></td>
<td></td>
</tr>
<tr>
<td><em>Never</em></td>
<td>15%</td>
</tr>
<tr>
<td><em>30 minutes</em></td>
<td>33%</td>
</tr>
<tr>
<td><em>1 hour</em></td>
<td>27%</td>
</tr>
<tr>
<td><em>More than 1 hour</em></td>
<td>24%</td>
</tr>
</tbody>
</table>
CHAPTER 3
RESULTS

Examination of Manipulation Check Variables

Table 2 presents the means and standard errors for the final average HR, RPE, number of verbalizations of enjoyment and frustration, and reports of engagement for each of the four experimental activities. The high PA conditions elicited a higher average HR than the low PA conditions ($M = 157.3$ BPM, $SE = 1.5$ versus $M = 93.8$ BPM, $SE = 1.5$), $F(1,84) = 896.9$, $p < .001$, $\eta^2_p = .91$. The intensity of the high PA conditions was estimated to be between 70 – 80% $HR_{max}$ ($HR_{max} = 208 - .7 \times$ age; Tanaka, Monahan, & Seals, 2001), indicating that the high PA conditions elicited moderate-intensity PA. The high PA conditions also elicited a higher level of perceived exertion than the low PA conditions ($M = 6.4$, $SE = 0.3$ versus $M = 2.0$, $SE = 0.3$), $F(1,86) = 87.0$, $p < .001$, $\eta^2_p = .50$. The average RPE immediately after exergaming corresponded to the descriptor “tired”. CE had no effect on either HR or RPE ($F < 1$). The high CE conditions did elicit more verbalizations of enjoyment than did low CE ($M = 7.1$, $SE = 0.7$ versus $M = 2.2$, $SE = 0.7$), $F(1,87) = 26.2$, $p < .001$, $\eta^2_p = .23$. High CE also elicited more verbalizations of frustration than low CE ($M = 10.9$, $SE = 0.7$ versus $M = 0.7$, $SE = 0.7$), $F(1,87) = 118.0$, $p < .001$, $\eta^2_p = .58$. PA had no effect on either the verbalizations of enjoyment or frustration ($p > .10$). Finally, high CE elicited a higher report of engagement than low CE ($M = 5.1$, $SE = 0.2$ versus $M = 2.9$, $SE = 0.2$), $F(1,87) = 48.4$, $p < .001$, $\eta^2_p = .36$. Likewise, high PA elicited a higher report of engagement than low PA ($M = 4.3$, $SE = 0.2$ versus $M = 3.7$, $SE = 0.2$), $F(1,87) = 4.6$, $p = .04$, $\eta^2_p = .05$. These main effects were superseded by a significant
PA X CE interaction, $F(1,87) = 6.0, p = .02, \eta^2_p = .07$. This interaction indicated that children reported the highest level of engagement after the two high CE conditions (i.e., Mario and Mini-Exergames), an intermediate level of engagement after playing Marathon (high PA, low CE), and the lowest level of engagement after watching the video (low PA, low CE). Taken together, the results of these analyses indicate that overall CE and PA were successfully manipulated by the four experimental conditions; however, there is some indication, based on children’s reports, that Marathon may have been more engaging than expected.

**Effects on ANT-C Performance**

ANT-C data from two children could not be used due to technical problems during the second block of the ANT-C during one or more experimental sessions. Without data from the second block, reliable estimates of the ex-Gaussian parameters could not be computed. There were no significant interactions between experimental activity and age, gender, or testing context ($p > .25$) on ANT-C performance, indicating that the effect of the experimental activities on cognitive performance was similar across these between-subjects variables. Thus, these variables were not included in the main analyses.

Table 3 presents the RT parameter estimates and accuracy by the two flanker types separated by the four experimental activities. Figure 2 shows the results of the main effects analyses in graphical form. On incongruent trials, which assess how well children deal with interfering stimuli, high PA decreased mean RT from 775.5 ms to 742.2 ms, $F(1,87) = 5.97, p < .02$, $\eta^2_p = .06$, and decreased $\mu$ from 612.9 ms to 576.3 ms, $F(1,87) = 6.11, p < .02$, $\eta^2_p = .07$. Together, these two findings indicate that PA had a general enhancing effect on the entire incongruent RT distribution and increased the speed of the fastest responses in the distribution. PA and CE interacted only on the incongruent $\tau$ score, $F(1,87) = 6.26, p < .02$, $\eta^2_p = .07$. Follow-
up analysis of simple effects showed that CE alone (i.e., playing Mario) increased \( \tau \) (unusually slow responses) relative to watching the video from 115.6 ms to 173.6 ms, \( t(87) = 2.7, p < .01 \), but that there were no significant differences between the two exergames (Marathon: 165.3 ms; Mini-Exergames: 147.3 ms), \( t < 1 \). As shown in Figure 3, these results suggest that PA mitigates the negative effect CE alone has on \( \tau \) but do not indicate that the combination of PA and CE improved task performance over PA alone. On congruent trials, which have minimal EF demands, PA decreased \( \tau \) from 170.9 ms to 135.8 ms, \( F(1,87) = 7.14, p < .01, \eta_p^2 = .08 \). This finding indicates that PA reduced skew in the right tail of the congruent RT distribution, signifying fewer unusually long responses. CE had no significant effect on any incongruent or congruent parameter (\( p > .05 \)).

To examine the effects on EF selectively, interference scores were calculated by subtracting a given performance parameter on congruent trials from its corresponding parameter on incongruent trials. The mean values of these interference scores are displayed in Table 4. PA decreased the \( \mu \) interference score from 77.8 to 33.2 ms, \( F(1,87) = 9.19, p < .01, \eta_p^2 = .10 \), but increased the \( \tau \) interference score from -26.5 to 20.8 ms, \( F(1,87) = 4.61, p = .01, \eta_p^2 = .07 \). Figure 4 shows PA’s effect on mu and tau interference values. The decrease in the \( \mu \) interference score suggests that the difference in the leading edge between the incongruent and congruent RT distributions is reduced following high PA relative to low PA. In other words, the cost of incongruent flanking fish to children’s fastest RT, relative to congruent flanking fish, is less following high PA than following low PA. The increase in the \( \tau \) interference score suggests that the difference in the skew in the right tail of the RT distribution (representing unusually slow responses) between the incongruent and congruent RT distributions is increased following high PA relative to low PA. This latter finding was expected given that PA had no effect on the entire
distribution mean ($M$); that is, since the $M$ interference score was roughly equivalent between low and high PA, a reduction in $\mu$ had to be offset by an increase in $\tau$. Furthermore, the analyses of incongruent and congruent trials separately indicated high PA decreased $\tau$ on congruent trials only—which would increase the interference score—but did not indicate that PA had a negative effect on $\tau$ on incongruent trials. To aid in understanding these effects specific to EF, Figure 5 shows how high and low PA affected the incongruent flanker RT distribution relative to the congruent flanker RT distribution. High PA’s decrease of the mu interference score is evident in the greater overlap of the incongruent and congruent distributions in the right panel in comparison to less overlap after low PA (shown in the left panel). CE had no effect on any interference score, nor were there significant interactions ($p > .10$).
Table 2

*Means (and Standard Errors) for Manipulation Check Variables*

<table>
<thead>
<tr>
<th></th>
<th>Low PA</th>
<th>High PA</th>
<th>Mini-Exergames</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Video (Low CE)</td>
<td>Mario (High CE)</td>
<td>Marathon (Low CE)</td>
</tr>
<tr>
<td>Final average heart rate (bpm)</td>
<td>93.1&lt;sup&gt;a&lt;/sup&gt; (2.5)</td>
<td>94.2&lt;sup&gt;a&lt;/sup&gt; (2.2)</td>
<td>154.8&lt;sup&gt;b&lt;/sup&gt; (3.8)</td>
</tr>
<tr>
<td>Final perceived exertion (0-10)</td>
<td>2.2&lt;sup&gt;a&lt;/sup&gt; (0.5)</td>
<td>2.0&lt;sup&gt;a&lt;/sup&gt; (0.3)</td>
<td>6.7&lt;sup&gt;b&lt;/sup&gt; (0.6)</td>
</tr>
<tr>
<td>Overt engagement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enjoyment</td>
<td>0.8&lt;sup&gt;a&lt;/sup&gt; (0.3)</td>
<td>7.0&lt;sup&gt;c&lt;/sup&gt; (1.6)</td>
<td>3.6&lt;sup&gt;b&lt;/sup&gt; (1.3)</td>
</tr>
<tr>
<td>Frustration</td>
<td>0.1&lt;sup&gt;a&lt;/sup&gt; (0.1)</td>
<td>10.2&lt;sup&gt;b&lt;/sup&gt; (1.3)</td>
<td>1.3&lt;sup&gt;a&lt;/sup&gt; (0.6)</td>
</tr>
<tr>
<td>Reported Engagement</td>
<td>2.2&lt;sup&gt;a&lt;/sup&gt; (0.3)</td>
<td>5.1&lt;sup&gt;c&lt;/sup&gt; (0.3)</td>
<td>3.6&lt;sup&gt;b&lt;/sup&gt; (0.4)</td>
</tr>
</tbody>
</table>

*Note.* Values that share a common superscript are not significantly different at $p < .05$. 
Table 3

*Means (and Standard Errors) for Performance Measures on the Child ANT*

<table>
<thead>
<tr>
<th></th>
<th>Low PA</th>
<th>High PA</th>
<th>Mini-Exergames</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Video (Low CE)</td>
<td>Mario (High CE)</td>
<td>Marathon (Low CE)</td>
</tr>
<tr>
<td><strong>Incongruent</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$M$</td>
<td>749.4$^{a,b}$</td>
<td>765.8$^b$</td>
<td>745.3$^{a,b}$</td>
</tr>
<tr>
<td></td>
<td>(25.2)</td>
<td>(21.4)</td>
<td>(26.7)</td>
</tr>
<tr>
<td>$\mu$</td>
<td>633.8$^a$</td>
<td>592.2$^{a,b}$</td>
<td>580.0$^b$</td>
</tr>
<tr>
<td></td>
<td>(24.2)</td>
<td>(18.6)</td>
<td>(17.1)</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>109.4$^a$</td>
<td>68.8$^b$</td>
<td>70.2$^b$</td>
</tr>
<tr>
<td></td>
<td>(17.2)</td>
<td>(9.7)</td>
<td>(9.6)</td>
</tr>
<tr>
<td>$\tau$</td>
<td>115.6$^a$</td>
<td>173.6$^b$</td>
<td>165.3$^b$</td>
</tr>
<tr>
<td></td>
<td>(15.2)</td>
<td>(19.5)</td>
<td>(17.1)</td>
</tr>
<tr>
<td><strong>Accuracy</strong></td>
<td>94.6%$^a$</td>
<td>93.4%$^a$</td>
<td>94.6%$^a$</td>
</tr>
<tr>
<td></td>
<td>(0.01)</td>
<td>(0.01)</td>
<td>(0.01)</td>
</tr>
<tr>
<td><strong>Congruent</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$M$ (SD)</td>
<td>700.2$^{a,b}$</td>
<td>712.8$^b$</td>
<td>688.5$^{a,b}$</td>
</tr>
<tr>
<td></td>
<td>(21.4)</td>
<td>(23.4)</td>
<td>(24.2)</td>
</tr>
<tr>
<td>$\mu$</td>
<td>542.6$^a$</td>
<td>528.5$^a$</td>
<td>545.8$^a$</td>
</tr>
<tr>
<td></td>
<td>(16.8)</td>
<td>(16.1)</td>
<td>(17.0)</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>76.1$^a$</td>
<td>61.2$^a$</td>
<td>67.8$^a$</td>
</tr>
<tr>
<td></td>
<td>(12.4)</td>
<td>(9.8)</td>
<td>(8.8)</td>
</tr>
<tr>
<td>$\tau$</td>
<td>157.6$^{a,b}$</td>
<td>184.3$^a$</td>
<td>142.7$^b$</td>
</tr>
<tr>
<td></td>
<td>(16.7)</td>
<td>(16.2)</td>
<td>(16.4)</td>
</tr>
<tr>
<td><strong>Accuracy</strong></td>
<td>97.3%$^a$</td>
<td>96.2%$^a$</td>
<td>98.0%$^a$</td>
</tr>
<tr>
<td></td>
<td>(0.01)</td>
<td>(0.01)</td>
<td>(0.01)</td>
</tr>
</tbody>
</table>

*Note.* Values that share a common superscript are not significantly different at $p < .05$. The unit of measurement for the mean and ex-Gaussian parameters is milliseconds.
Table 4

Means (and Standard Errors) for Interference Scores on the Child ANT

<table>
<thead>
<tr>
<th></th>
<th>Low PA</th>
<th></th>
<th>High PA</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Video</td>
<td>Mario</td>
<td>Marathon</td>
<td>Mini-Exergames</td>
</tr>
<tr>
<td></td>
<td>(Low CE)</td>
<td>(High CE)</td>
<td>(Low CE)</td>
<td>(High CE)</td>
</tr>
<tr>
<td>( M )</td>
<td>49.2(^a)</td>
<td>53.0(^a)</td>
<td>56.8(^a)</td>
<td>51.3(^a)</td>
</tr>
<tr>
<td></td>
<td>(10.3)</td>
<td>(8.0)</td>
<td>(10.9)</td>
<td>(8.2)</td>
</tr>
<tr>
<td>( \mu )</td>
<td>91.2(^a)</td>
<td>63.7(^{ab})</td>
<td>34.2(^b)</td>
<td>32.8(^b)</td>
</tr>
<tr>
<td></td>
<td>(19.3)</td>
<td>(12.5)</td>
<td>(12.3)</td>
<td>(13.2)</td>
</tr>
<tr>
<td>( \sigma )</td>
<td>34.0(^a)</td>
<td>15.9(^a)</td>
<td>8.1(^a)</td>
<td>4.1(^a)</td>
</tr>
<tr>
<td></td>
<td>(14.6)</td>
<td>(11.7)</td>
<td>(9.4)</td>
<td>(13.2)</td>
</tr>
<tr>
<td>( \tau )</td>
<td>-42.1(^a)</td>
<td>-10.7(^{ab})</td>
<td>22.6(^b)</td>
<td>18.5(^b)</td>
</tr>
<tr>
<td></td>
<td>(22.3)</td>
<td>(15.4)</td>
<td>(12.0)</td>
<td>(17.9)</td>
</tr>
<tr>
<td>Accuracy</td>
<td>-2.7%(^a)</td>
<td>-2.8%(^a)</td>
<td>-3.4%(^a)</td>
<td>-2.0%(^a)</td>
</tr>
<tr>
<td></td>
<td>(0.01)</td>
<td>(0.01)</td>
<td>(0.01)</td>
<td>(0.01)</td>
</tr>
</tbody>
</table>

*Note.* Interference scores were calculated for each independent variable by subtracting the child’s congruent score from the incongruent score. The unit of measurement for the mean and ex-Gaussian parameters is milliseconds. Values that share a common superscript are not significantly different at \( p < .05 \).
Figure 1. The ex-Gaussian approach to RT data analysis.

Note. (A) The ex-Gaussian distribution (purple) is the convolution of Gaussian (blue) and exponential (red) functions. (B) Reductions in overall mean RT could result from decreased mu (red) or from decreased tau (blue). (C) A typical RT distribution from the Child ANT demonstrates its ex-Gaussian shape, and (D) a plot of the observed against the expected quantile values shows that the ex-Gaussian distribution predicted the empirical data well, $R^2 = .988$. 
Figure 2. Main effects of physical activity and cognitive engagement.

Note. (A) The main effects are shown for mean RT and mu; (B) for sigma and tau; (C) and for accuracy. Error bars represent standard errors. ** p < .01. * p < .05.
Figure 3. Interaction effect on incongruent tau parameter.

Note. Error bars represent standard errors.
Figure 4. Significant main effects of physical activity on the interference scores.

Note. ** $p < .01$. * $p < .05$. 
Figure 5. The RT distributions for congruent and incongruent flanker trials.

**Note.** The greater overlap of the normal component of the incongruent RT distribution (in red) and congruent RT distribution (in blue) following high PA (B) in comparison to low PA (A) demonstrates that high PA reduced the $\mu$ interference score.
CHAPTER 4
DISCUSSION

The current study suggests that physical activity may be an important, understudied, aspect of children’s daily experience that contributes to the development of executive function. The results demonstrated that a single bout of PA, in the form of exergaming, enhances children’s EF across a wide age range. Specifically, PA reduces the negative effect that potentially distracting incongruent visuospatial stimuli have on children’s efficiency to make a goal-directed response to a central stimulus. Moreover, this study is the first to directly show the specific site of improvement: The fact that the effect was evident in the $\mu$ parameter, which characterizes the leading edge of the RT distribution, shows that PA improves children’s efficiency to resolve visuospatial conflict rather than reduce lapses in attention during the numerous trials of the task. In addition, because PA was compared not only to “mindless” rest (i.e., watching an educational video) but also to playing a cognitively-engaging, sedentary video game, the current study is the first to show that only the PA component of exercise, and not CE, enhances this aspect of EF.

It has been suggested that PA increases physiological arousal, which in turn allows for greater allocation of attention to exert cognitive control over interference (Hillman et al., 2009). Physiological arousal represents in part transitory changes in neurotransmitter (e.g., dopamine, norepinephrine, and serotonin) release in the brain (Meeusen, Piacentini, & De Meirleir, 2001). These changes exert transient neuromodulatory effects that enhance certain aspects of EF (Robbins, 2000). The current study establishes that efficient interference control is one aspect of
EF sensitive to physiological arousal but that physiological arousal does not reduce the occurrence of lapses in attention across the task. Furthermore, the study shows that playing a cognitively-engaging sedentary game does not induce this same kind of physiological arousal.

The results of the current study did not show a main effect of CE on EF nor did the one significant interaction indicate that the combination of PA and CE has a stronger effect than PA alone. Importantly, this implies that previous findings showing that more complex types of PA improve cognitive functioning in comparison to repetitive PA (i.e., Pesce et al., 2009) may have resulted from the increased social interaction rather than an increase in cognitive engagement per se. In the context of PA, social interaction may encourage children to assess other participants’ mental states (e.g., intentions) in order to anticipate their upcoming actions either to play competitively or cooperatively (Best, in press). This ability to read others’ intentions—termed “theory-of-mind”—correlates with children’s EF performance, even when the executive demands of the theory-of-mind task ostensibly are eliminated (Perner, Lang, & Kloo, 2002).

That CE had no effect is quite interesting and suggests a unique ability of physiological arousal induced by vigorous PA to facilitate EF that does not occur by playing a challenging, cognitively-engaging sedentary video game. To emphasize this point, sedentary CE (playing Mario) required the execution of quick finger movements to operate a handheld controller but did not enhance subsequent EF performance, despite the fact that EF was assessed via quick button presses by the fingers. Although a previous study has shown improvements to EF following training (i.e., regular participation over several weeks or months) on challenging computerized games (Thorell et al., 2009), the current study suggests that a single training session is not sufficient in conferring such improvements.
An alternative explanation for why the combination of PA and CE did not have a stronger effect than PA alone lies in the complexity of the motor movements required to play the two exergames. Complex motor movements (e.g., performing dissimilar actions with one’s hands or sequencing and coordinating distinct movements), in particular, are thought to recruit neural circuitry associated with EF (Budde et al., 2008; Diamond, 2000; Serrien, Ivry, & Swinnen, 2007). This recruitment might prime EF for subsequent activities requiring controlled, goal-directed cognition and behavior. In the current study, whereas the complexity of movement during Mini-Exergames—coordinating running, jumping, and crouching—was intended to be significant, the complexity of movement during Marathon—jogging and/or walking in place on the response pad—was intended to be minimized. However, jogging on a response pad is most effective when the balls of the feet impact directly on the pressure-sensitive buttons, and therefore, requires the participant to continually monitor and adjust one’s position on the response pad and the jogging motion in order to move the virtual character most effectively. As a result, it is likely more complex than other types of repetitive jogging (e.g., jogging in place in a gymnasium or jogging around a track). Thus, the complexity of movement inherent in both exergames may have primed EF for performance on the ANT-C and resulted in similar cognitive performance after both exergames.

That limitation notwithstanding, video games, including exergames, proved to be an excellent experimental tool to manipulate PA and CE in an individualized context. Exergaming elicited an average HR over 23 minutes representing PA (70 – 80% of estimated HR_{max}). Furthermore, the two CE games elicited more verbal signs of enjoyment and frustration and were reported to be more enjoyable than the non-engaging activities. This increase in both frustration and enjoyment suggests that these CE activities were challenging enough to engage the children
without being too difficult to diminish their enjoyment. With continuing improvements to video gaming technology to accurately capture and translate children’s PA into the actions of the virtual player, video games will continue to offer a unique methodological tool to manipulate aspects of children’s PA while keeping tight control over other aspects. As an example, video game-based research could examine how PA that encourages cooperation versus competition affects cognition.

Whereas aspects of the RT distribution were sensitive to PA, accuracy was not, as children performed at a high level of accuracy across the conditions. This indicates that the effects on RT did not come at the expense of poorer accuracy (i.e., a speed-accuracy tradeoff). Given the selective effects on RT (see also Ellemberg & St. Louis-Deschênes, 2010), these results should encourage researchers to utilize the ex-Gaussian approach to examine the precise effects of PA (as well as other types of experimental manipulations) on children’s cognition. Not only can this approach confer greater power to the statistical tests being used, it can provide insight into how the experimental manipulation actually influences the aspect of cognition under study. As found in the current study, an experimental manipulation may enhance the efficiency of the fastest responses, presumably when the child is most attentive, without reducing lapses in attention; however, an opposite effect may also occur. In either scenario, an ex-Gaussian analysis should enhance the researcher’s conceptualization of how an experimental manipulation affects cognition. The ex-Gaussian approach has already proved valuable in examining lifespan developmental changes in EF (McAuley et al., 2006) and in characterizing the cognitive abilities in children diagnosed with attention-deficit hyperactivity disorder (Geurts, Grasman, Verté, Oosterlaan, Roeyers, Kammen, & Sergeant, 2008; Leth-Steensen, King Elbaz, & Douglas, 2000; Vaurio, Simmonds, & Mostofsky, 2009).
To my knowledge, a study by Davranche and her colleagues (2006) is the only previous research to use the ex-Gaussian approach to examine the effects of PA on cognition. In this study, young adults with significant experience participating in cognitively-engaging PA (e.g., team sports, racket games) performed a choice RT task while simultaneously engaging in moderate intensity stationary cycling. The choice RT task had participants perform either a stretching or flexing of the left or right wrist based on the randomly determined appearance of one of four visual stimuli. Demands on EF for this task are considered low because test trials are preceded by a learning period during which each stimulus is mapped to the specific motor response. Relative to performing the choice RT task while resting, concurrent PA reduced the participants’ overall mean RT and $\mu$ values—but not the $\sigma$ or $\tau$ values—without diminishing response accuracy. The authors conclude that these results indicate that PA shifts the entire RT distribution without altering its shape, thereby representing a generalized effect on choice RT.

Although the significant differences in exercise protocol, cognitive assessment, and sample population disallow direct comparisons with the results of the current study, together the two studies suggest that the ex-Gaussian approach can be a valuable tool to examine the specific effects of PA on cognition and to further our conceptualization of how PA impacts cognition.

The current study’s unpacking of physiological and cognitive aspects of children’s activity is important for both theoretical and practical reasons. Regarding theory, the current findings draw attention to PA’s influence on children’s EF, adding to the list of daily childhood experiences that may contribute to the development of EF. Whereas research on early cognitive development often recognizes the coupling of movement and cognition (e.g., Robertson & Johnson, 2009), developmental research on older children typically pays little attention to this coupling, despite experimental evidence for its importance (Best, in press; Tomporowski, 2003;
The current study highlights the physiological arousal induced by PA and the complexity of physical movement as mechanisms by which PA influences EF. Regarding practice, the findings provide compelling evidence that children should participate in PA to prime EF in order to resolve interference in the environment and respond selectively in accordance of a desired goal. Along with recent calls to include classroom activities that spark children’s emotional interest in subject matter in order to enhance children’s EF (Blair & Diamond, 2008), the current results suggest that PA be included in the classroom. In support of this idea, Donnelly et al. (2009) found that incorporating PA into existing classroom lessons (“Physical Activity Across the Curriculum”) improved elementary school children’s performance on several academic achievement tests in comparison to children enrolled in a traditional classroom curriculum. Although the researchers did not determine that improved academic achievement resulted specifically because learning was enhanced when it occurred in the context of PA, it is plausible that enhanced learning via heightened EF partially explains the effect.

Viewed from a different perspective, the results of this study suggest that engaging in sedentary activities such as watching television or playing sedentary video games may result in children being under-aroused and therefore less efficient at resolving interference in the environment. From this perspective, the fact that children spend a significant amount of time in sedentary behavior (Sisson et al., 2009) may have negative ramifications not only for their physical development but also for their cognitive development, including the quality of their learning experiences. Sedentary children’s EF may be sub-optimal, resulting in a broad negative impact on their functioning and development. It is important that all those concerned with
children’s development consider the potential consequences of physical activity and inactivity on cognitive functioning.
REFERENCES


