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FIT Kids: Time in target heart zone and cognitive performance

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ABSTRACT

This present study examined time spent in the target heart zone (THZ) and its relationship to tasks requiring variable amounts of executive control function in prepubescent children participating in a 9-month randomized controlled physical activity program. A sample of 59 participants performed the Stroop Color-Word Test and the Comprehensive Trail Making Test cognitive assessments. Heart rate data were collected during participation in the physical activity program using E600 heart rate monitors (Polar, Finland). Analysis of these data revealed that time above the THZ, representing vigorous physical activity, was a predictor of performance in some of the cognitive tasks and task conditions. These results suggest that heart rate, as a measure of physical activity intensity, should be closely monitored during research that is intended to make inferences about its effects on cognitive performance as participation in vigorous activities may have specific benefits over lower intensities among prepubescent children.

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Physical activity has many known benefits for children such as improved physical fitness and reduced risk of disease (Strong et al., 2005), yet at least one-third of children do not meet the national guidelines of 60 min of moderate to vigorous activity each day (Centers for Disease Control and Prevention [CDC], 2008). Schools are an ideal place to provide interventions since 98% of children spend approximately six hours each day in attendance (U.S. Census Bureau, 2006). Further, physical activity (Hillman et al., 2009a,b; Donnelly et al., 2009) and physical fitness (Hillman et al., 2005) are associated with success in schools through better attendance (Welk et al., 2010), attention (Mahar, 2006), and academic achievement (Castelli et al., 2007). Study of the relationship between physical activity and cognitive performance has been around for decades with early research focusing on adult physical fitness and reaction time. The first in-school physical activity study, examined the effects of exertion during physical education class on mathematical computations in second grade students (Gabbard and Barton, 1979). Initial studies such as these were either atheoretical or grounded in the speed hypothesis, which posits that physically active humans would respond faster to simple cognitive tasks than healthy, but inactive humans. Although these studies are considered seminal research, the generalizability is limited because the speed hypothesis did not necessarily account for the complexity of tasks required for achievement in school.

Executive control has been evidenced in children as young as 12 months old, with age 3.5 generally being the time when behavioral response becomes observable, yet executive function continues to develop until the early twenties (Wiebe et al., 2010). Recently, the executive function hypothesis has been applied to children when comparing processing speed and accuracy to adults (Hillman et al., 2005), investigating inhibitory control tasks (Buck et al., 2008), and examining brain function (Pontifex et al., in press) and structure (Chaddock et al., 2010a,b). Further, the relationship between physical activity and executive function has been examined from both the acute (Hillman et al., 2009a,b) and chronic perspectives (Davis et al., 2007) suggesting that a dose–response relationship may exit. Higher doses (40 min of physical activity for 15 weeks) resulted in significantly better performance in planning tasks over low doses (no physical activity). While Hillman et al. (2009a,b) found a single bout of light to moderate, treadmill walking can transiently improve executive function beyond that associated with sedentary behaviors. Evidence of a dose–response relationship between physical activity and executive function suggests that the intensity of engagement should be closely monitored during the intervention. Given its linear relationship with oxygen uptake (VO_2), heart rate telemetry can be used to accurately track physical activity engagement in children (Bassett, 2000; Freedson et al., 2000; Laukkanen and Virtanen, 1998). Technological advances allow heart rate monitors to measure exercise intensity, time in the target heart zone, and energy expenditure during participation in school physical activity programming.

Although, the dose–response research is promising it is difficult to transfer these findings directly into instructional practice. Educational reform should address student health issues through the creation of policy, inclusion of physical activity across the curriculum, and best practice (Castelli and Beighle, 2007); however, before this can happen, we need to know what frequency, intensity, time, and type

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of physical activity is worth recommending. Accordingly, the purpose of this study was to examine the relationship between the amount of time spent in the target heart zone (THZ) and performance on cognitive tasks requiring variable amounts of executive control function. As such, it was hypothesized that time in the THZ would mediate physical fitness effects and cognitive performance in a 9-month physical activity intervention among elementary-aged children. The secondary hypothesis was that time in the THZ would be associated with tasks requiring greater executive demands.

Methods

Design

The Fitness Improves Thinking or FIT Kids program is a part of a large-scale randomized controlled design created to improve the physical fitness of children, thus modulating enhanced cognitive performance. Although the FIT Kids program is part of a clinical trial, no heart rate data was available from the control group because their afterschool activities were not monitored on a daily basis. As such, this study should be considered a pre-post uncontrolled design, thus limiting the generalizability of these findings. However, given the lack of research on heart rate intensity and its relation to cognitive tasks, as well as the demographic make-up of the participants, this study is both timely and warranted.

Children from one Midwest County were recruited for participation in a 120-minute after school program located on the campus of a major university. The FIT Kids program was offered every day after school; however, participants did not attend on days of school closures and early dismissals, during which time the participants were given physical activity homework (i.e., a worksheet with a physical activity task and tracking system). From August to May there were 152 sessions of the FIT Kids program offered. A typical FIT Kids lesson centered around a health-related fitness theme such as nutrition or self-management and began with the initial physical activity requiring the participants to engage in a variety of fitness activities for up to 40 min. This was followed by a low intensity period that introduced an educational theme and consumption of a healthy snack and water. The remainder of the physical activity time was dedicated to motor skill development and low organizational game play targeting a skill theme (e.g., dribbling). The atmosphere was cooperative, but self-challenges were regularly issued for motivation and the tracking of progress. To date, two cohorts of participants have completed the program.

Participants

The heart rate, physical fitness, and cognitive performance scores of fifty-nine FIT Kids participants were utilized for this analysis. Table 1 contains all of the demographic and cardiorespiratory data of the participants. The participant ethnicity was similar to that of the county with 41% White, 30% Black, 15% Asian, and 14% Bi-racial or other ethnicities. Sixty percent of the children received free-reduced lunch. According to the Illinois Standardized Achievement Test (ISAT) and the Wide Range Achievement Test, 90% of the participants in this sample were reading at or above grade level and 95% were at or above grade level for mathematics. Children with known cognitive disabilities or individual education program (IEP) were excluded from participation in this study. Prior to testing informed consent was secured from the legal guardian and informed assent was secured from the child participant in accordance with the University of Illinois at Urbana-Champaign Institutional Review Board.

Table 1
Mean (SD) values for participant demographics and fitness data by gender.

Variable	All (n = 59)	Females (n = 26)	Males (n = 33)
Age (years)	8.79 (.54)	8.91 (.54)	8.69 (.52)
Tanner scale	1.55 (.53)	1.57 (.50)	1.53 (.57)
KBIT (IQ)	107.64 (12.06)	108.58 (13.74)	106.91 (10.71)
BMI (kg/m^2)	19.97 (4.85)	20.66 (3.97)	19.39 (5.44)
VO_2max (ml/kg/min)	38.13 (7.04)	35.50 (5.85)	40.13 (7.29)
HR max (bpm)	187.76 (11.24)	190.52 (11.15)	185.67 (10.73)
Mean OMNI RPE	7.45 (2.40)	7.32 (2.19)	7.55 (2.56)

Cognitive measures

Pre/post measures of four different cognitive assessments (Kaufman Brief Intelligence Test (KBIT); Wide Range Achievement Test (WRAT); Trail Making Test (Trails); and Stroop Color-Word Test) were analyzed in this study. Tasks were organized into high and low demands on executive function (Ariffa, 2007). Q9

The K-BIT (Kaufman and Kaufman, 1990) is a valid and reliable tool used to estimate verbal and nonverbal intelligence. This assessment measures both crystallized and fluid intelligence in children, provides an IQ composite score, and has cultural fairness. This test can be administered to participants ages 4–90 in an individual setting in approximately 20 min. Reliability ranges from .88 to .94.

The WRAT (Jastak and Jastak, 1978) is a brief achievement test measuring reading, spelling, and arithmetic computations. This is a standardized, clinical assessment used to screen for learning disabilities. It has been formed with over 15,200 subjects and is culturally sensitive.

The Comprehensive Trail Making Test (Reynolds, 2002; Smith et al., 2008) is a visual task requiring participants to connect circles in numerical and alphabetical order, by drawing a line from one point to the next. The object is to connect the dots as fast as possible with the resulting time being the score. If an error is made during the process, it must be corrected during the time sequence.

The Stroop Color-Word Test (Golden, 1978) was employed to examine Word, Color, and Color-Word conditions. Participants were given 45-seconds each to: (a) read words in black ink, (b) identify the color of the ink, and (c) name the color of an incompatible color-word pair (e.g., the word blue printed in green ink; requiring the inhibition of the prepotent response to read the word). The number of words read, after correcting for errors, was recorded as the score. An interference score was calculated using the Stoelting Q10 Co. (2003) children's color-word test software.

These cognitive tasks and task conditions were organized according to low and high executive function demands for analysis purposes. The low executive function tasks were the first two conditions of the Stroop test (Word and Color) and Trail Making Part A, as these tasks required less attention, memory, and/or mental flexibility. The high executive function tasks included Stroop Color-Word and Trail Making Part B. These tasks incorporate the contextual interference increasing the demand on executive processes.

Cardiorespiratory fitness assessment

Cardiorespiratory fitness was assessed through indirect calorimetry to determine maximal oxygen consumption (VO_2max). Using a modified Balke protocol (ACSM, 2006) and ParvoMedics True Max 2400 metabolic system, Q11 measures of oxygen uptake (VO_2) and respiratory exchange ratio (RER) were recorded every 30-seconds from the participant on a motor driven treadmill. Workload was increased by 2.5% every 2 min until volitional exhaustion. A Polar heart rate (HR) monitor (Model A1, Polar Electro, Finland) captured HR throughout the protocol. The children's OMNI scale (Utter et al., 2002) was used to collect a child's ratings of perceived exertion (RPE). Using the range of numbers 1–10 and child-like pictures, this scale quantified how tired the child was during the exercise testing. See Table 1 for the cardiorespiratory results.

Pubertal timing

The Tanner scale of physical development in children and adolescents (Taylor et al., 2001) was used to determine that all participants were in the Q12 prepubescent stage of maturation. The scale is based on the secondary sex characteristics of pubic hair (both male and female), genitals (males) and breasts (females). Child participants, in the presence of a guardian, identified their stage of developmental using Tanner scale illustrations.

HR data during the intervention

Upon arrival via bus transportation directly from school to a campus recreational center, each participant put on either a heart rate monitor or pedometer. The participants had been familiarized in how to wear, store, and start the HR monitors. The type of monitoring device worn by the participant rotated by day and unit to minimize participant's burden as well as maintain motivation and exercise adherence. At least two measures of HR were secured

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for the lessons within a given theme (e.g., an instructional unit on cardio-respiratory endurance). Polar heart rate monitors (E600, Polar Electro, Finland) are the most accurate when compared with metabolic system (Leger and Thivierge, 1988; Terbizan et al., 1999) and were therefore selected for use in this study. The E600 series is designed for group exercise sessions, so each participant could put his/her monitor on in a private setting, but the device could be read by the physical activity leader to ensure correct use. The accuracy of the HR monitor was confirmed by the watch of physical activity leader, who moved within close proximity to each participant, during the first few minutes of activity. If the HR monitor was not working adjustments were made with staff assistance. Time below-, time in-, and time above-the THZ were recorded. Watches were set to 55%–80% of an individual's max HR collected during the fitness testing. Data were uploaded following each physical activity session and were time dated and linked to lesson content.

Statistical analysis

A comprehensive battery of baseline and post intervention assessments were conducted on children as part of the randomized controlled design that increased the physical activity of children through the FIT Kids after school program. This study examined data from only the treatment group participants who provided HR data during the FIT Kids intervention ($N = 59$). In the preliminary data analysis, these data were examined for normal distribution and partial correlations controlling for age to identify associations among the variables. Paired t-tests and one-way analysis of variance (ANOVA) were utilized to examine pre/post treatment differences between the cognitive variables. To determine the associations between the cognitive variables, heart rate, and aerobic fitness the performance on the post-test was subtracted from the pre-test, for each variable and Pearson Product-Moment correlations were conducted. The relationships were further decomposed by the amount of executive control function required by each task. Multiple regressions were used to assess the contribution of demographic variables, physical fitness, and HR data to cognitive tasks requiring higher and lower amounts of executive control function. An alpha level of .05 was set prior to analysis.

Results

Paired t-tests revealed significant differences between pretest and posttest ($p < .01$) for VO_2max, all Stroop conditions, and Trail Making A and B tests (see Table 2). Results comparing physical fitness and the control group scores are reported elsewhere (Kamijo et al., submitted for publication). The ANOVA confirmed a significant difference $F(1, 58) = 7.44$, $p < .009$ between males and females for relative VO_2max, but not absolute ($p = .69$) or percent VO_2max ($p = .73$). There was no significant difference in BMI.

Table 3 displays the Pearson Product-Moment correlations between the variables. Partial correlations controlling for age, demonstrated significant associations between the percentage of time above the THZ for the Trails B ($p < .001$) and Stroop Color-Word condition ($p = .02$). A significant association was found between Trails A and mean HR ($p = .03$). There were no other significant correlations observed among the cognitive variables. Partial correlations between HR and post VO_2max testing found no significant relationships.

Table 2
Paired *T*-test analysis of mean difference.

Variable	Pre (1, 57)	Post (1, 57)	t
VO_2max – rel (ml/kg/min)	36.19 (7.47)	38.13 (7.04)*	3.34
VO_2max – abs (l/min)	1.34 (.29)	1.54 (.35)*	8.11
VO_2max –%	15.60 (18.83)	17.90 (19.73)	1.13
Stroop Word	64.05 (12.30)	70.95 (12.20)*	6.47
Stroop Color	40.33 (9.81)	46.93 (11.05)*	5.41
Stroop Color-Word	20.57 (6.04)	25.62 (7.43)*	6.36
Trails A	68.17 (20.34)	53.69 (17.31)*	7.34
Trails B	98.81 (34.57)	76.45 (30.78)*	7.31

* $p < .01$.

Table 3
Pearson Product-Moment correlations for cognitive tasks.

High executive function demands	Stroop Color-Word r		Trails B r
Physical Fitness			
VO_2max – rel (ml/kg/min)	−.10		.09
VO_2max – abs (l/min)	−.17		.14
VO_2max – (%)	−.02		.02
Time in THZ			
Mean below (%)	.03		.04
Mean in (%)	−.01		.06
Mean above (%)	−.28[a]		−.33[b]
Mean HR (bpm)	.17		.01
Low executive function demands	**Stroop-Word r**	**Stroop-Color r**	**Trails A r**
Physical fitness			
VO_2max – rel (ml/kg/min)	.01	.13	.03
VO_2max – abs (l/min)	.01	.11	.14
VO_2max – (%)	−.03	.02	.06
Time in THZ			
Mean below (%)	−.04	.02	.21
Mean in (%)	−.15	−.07	−.03
Mean above (%)	.19	−.02	−.16
Mean HR (bpm)	.08	−.07	−.27[c]

[a] $p = .02$.
[b] $p < .01$.
[c] $p = .03$.

To further assess the contribution of HR and other demographic variables on cognitive performance, demographic and then HR variables were regressed on to the correlated Stroop Color-Word, Trails B, and Trails A tests using a stepwise regression. The stepwise regression for Stroop Color-Word condition revealed a significant $R^2 = .29$ for KBIT, age, and mean time above the THZ, $F(1, 56) = 5.21$, $p = .02$. For Trails B, KBIT and mean time above the THZ were significant predictors, $F(1, 56) = 7.60$, $p < .01$ accounting for $R^2 = .35$ of the variance. There were no significance predictors identified for performance on the Trails A.

Discussion

Findings of this research demonstrate that an after school physical activity program can substantially increase aerobic fitness of its participants. Given the current obesity epidemic and risk for metabolic disease, this is noteworthy. Participants spent more than 53% of the 120 min engaging in a moderate physical activity, with another 11% of time engaged in vigorous physical activity. On average, from August to May child participants in the FIT Kids program were physically active for more than 75 min per weekday, thus exceeding the national physical activity guidelines. Despite this level of engagement, BMI was not significantly different at the end of the program. Similar to findings in the Physical Activity Across the Curriculum (PAAC) study, whereby a physical activity intervention increased engagement but did not significantly change BMI (Donnelly et al., 2010).

It was predicted that HR would be a significant contributor to improved cognitive performance resulting from increased aerobic fitness. The subsample of participants, selected for this analysis because they provided HR data during their program participation, significantly improved aerobic fitness. In addition, significant improvement was evidenced in each of the cognitive tasks examined in this present study; however, there is little evidence that HR or time within the THZ was a direct factor in these performance improvements. Secondarily, time in the THZ was not associated with tasks of greater executive demand. Instead, time above the THZ or the amount of time spent in vigorous physical activity was a predictor of performance. Since Hillman et al. (2009a,b) had found improved accuracy in cognitive tasks after light to moderate physical activity, it was unexpected that there would only be significant associations between

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heart rate that was above the THZ and cognitive tasks with high demands of executive function. It was surprising to find that only vigorous physical activity was associated with the cognitive tasks.

Children's participation in physical activity is different from that of adults, as they incrementally waver between low and high intensities, through short bursts of movement. At this age, the information revealed by using HR monitors is often more useful for the physical activity leader, than the child. Yet, emerging technologies that are specifically designed to give learners of this age immediate feedback on his/her physical activity levels (i.e., POLAR activity monitor) may have great potential. Specifically, these devices prompt the learner to move when they have not met their physical activity goals. The POLAR activity monitor has a digital figure that runs when the child runs or sits when the child is inactive. Use of these devices is worth investigating, if it means that the provision of feedback would result in more time spent in vigorous physical activities.

Cognitive improvement in executive function tasks with both high and low demands were associated with age, IQ, and mean time above the THZ. The contribution of mean time above the THZ presents a fascinating finding. Coe (2006) discovered that among physical education programs examined, only 19 min were spent engaged in physical activity. In that context, there were associations between physical activity and academic performance, but only for those who engaged at a vigorous level of physical activity. Further, Davis et al. (2007) suggested that high doses of physical activity (i.e., 40 min) produced significantly better cognitive performance than lower doses. However, light to moderate physical activity has been shown to transiently increase cognitive performance following a single, 20-minute bout of physical activity (Hillman et al., 2009a,b).

Studies using rodent models found that this frequency and duration of physical activity would have resulted in increased brain-derived neuotropic factor (BDNF) from increased stimulation of the hippocampal structures of the brain (Oliff et al., 1998), which has rich projections to prefrontal cortex, an area of the brain known to mediate executive control function. Although, well beyond the scope of this study it is unclear if these responses were elicited in children. Further, elite athletes can increase BNDF in a single session of near maximal exercise; however, these effects subside almost immediately following HR recovery (Vega et al., 2006). Perhaps work by Chaddock et al. (2010a,b) may shed light on other plausible explanations to the effects of physical fitness on cognitive performance. Magnetic resonance imaging (MRI) data in children illustrated larger bilateral hippocampal volume and superior relational task performance in aerobically fit over unfit children. In a second study, greater basal ganglia volume and superior task performance were found in fit children suggesting that physical fitness may have benefits to brain structure and function, well beyond those evidenced in behavioral tasks.

Despite unanticipated outcomes of this research study, the findings are contributory toward an emerging line of inquiry attempting to refine physical activity programming for children to enhance cognitive function. Vigorous activities offered in shorter bouts (less than 40 min) may help to facilitate the enhancement of cognitive performance. Accordingly, future physical activity interventions may want to consider formatting delivery in a manner that is different from the national physical activity guidelines and is more child-like or intermittent.

Limitations

This study is not without limitations. First, because data for the control group was reported elsewhere, direct comparison could not be made within this study. Second, the use of heart rate as a means to estimate energy expenditure and intensity is limited by (a) the emotional influences of the participant, (b) variation in age and fitness, and (c) the difference between upper and lower body limbs use during exercise (Freedson and Miller, 2000). Given that children tend to utilize their entire body during activity, the third limitation has the least application. Further, age and fitness differences are reported in this current study. The effects of the emotional state of the child were not specifically accounted for in this research; however, given the length of the intervention, if a child was having a 'bad day', they were permitted to remove his/her heart rate monitor. Despite these limitations, findings from this study suggest that engagement in vigorous physical activity has cognitive benefits associated with increased aerobic fitness.

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