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Physical Activity and Cognitive Functioning Relationship in Children

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***Abstract*—**This study investigated the relation between processing information and fitness level of active (fit) and sedentary (unfit) children drawn from rural and urban areas in Botswana. It was hypothesized that fit children would display faster simple reaction time (SRT), choice reaction times (CRT) and movement times (SMT). 60, third grade children (7.0 – 9.0 years) were initially selected and based upon fitness testing, 45 participated in the study (15 each of fit urban, unfit urban, fit rural). All children completed anthropometric measures, skinfold testing and submaximal cycle ergometer testing. The cognitive testing included SRT, CRT, SMT and Choice Movement Time (CMT) and memory sequence length. Results indicated that the rural fit group exhibited faster SMT than the urban fit and unfit groups. For CRT, both fit groups were faster than the unfit group. Collectively, the study shows that the relationship that exists between physical fitness and cognitive function amongst the elderly can tentatively be extended to the pediatric population. Physical fitness could be a factor in the speed at which we process information, including decision making, even in children.

***Keywords*—**Decision making, fitness, information processing, reaction time, cognition movement time.

I. Introduction

LATELY, the importance of a physically active lifestyle is receiving increased attention. The major benefits of physical activity for improved cognitive performance have been found amongst the elderly population [1], [2]. Similarly, recent findings have indicated that fitness may be related to academic achievement amongst children [3], [4]. Being physically inactive has an independent risk factor for cardiovascular disease as well as other health-related illnesses [5]. Physical activity benefits all regardless of age. It should be noted that due to modern lifestyle, which is sedentary, children tend to spend more time watching TV and playing computer games. Such lifestyle practices deny children physical activity, something that is characteristic of their developmental period. According to the guidelines referring to physical activity in a report from the World Health Organization and Fonds Gesundes Osterreich [6], children should devote at least 60 min a day to physical activity such as going to school on foot, walking up-stairs, and cycling. This will result in children developing strong muscles and bones. Furthermore, children who do not engage in physical exercise on a regular basis will never develop fully their genetic potential in terms of their motor skills [7]. More importantly, the US National Association for Sport and Physical Education (NASPE) report of 2010 emphasized that children should spend as much time as possible engaging in activities that require physical movement.

A meta-analysis [2] provides support of improvement in cognition amongst children as a result of physical activity. The meta-analysis study quantitatively combined and examined the relationship of studies pertaining to physical activity and cognition in children. Cognitive assessments in the meta-analysis study included academic readiness, IQ, math, verbal and memory tests, and the age group was middle-aged and high-school aged children. According to these findings, fitness may be related to general cognitive function improvements; however, they do not offer any clear explanation of the underlying mechanisms of how aerobic fitness affect cognitive functioning in children. So far, few studies have investigated the cognitive component of information processing speed and fitness level of active and sedentary children. Examining this potential relationship is important, as responding quickly is essential to performing some basic activities such as crossing a street, driving a car or simply avoiding eminent danger. Thus, faster reaction results from the way the individual processes information and subsequently initiates the required action.

The California Department of Education (CDC) [8] conducted a study to identify relationship between physical fitness and academic achievement. Math and reading scores from Stanford Achievement Test (SAT) were individually matched with fitness scores from Fitnessgram [9] of 353,000 fifth graders and 322,000 seventh graders. The study yielded a positive relationship between physical fitness and SAT scores across all grade levels, whereby those children with high levels of fitness were concomitant with higher academic achievement. Elsewhere, Coe, et al. [10] extended the CDE findings by observing relationship between vigorous physical activity and higher grades in school. Hillman et al. [3] linked aerobic fitness to improvements in neuroelectric and behavioral performance of children during a stimulus discrimination task. The study concluded that higher fit children exhibited greater allocation of attentional resources to working memory, thus supporting the fitness and cognition association research on adult populations [11]. Other studies in support of the fitness-cognition relationship [12], [14]-[17] have found a positive relationship between physical activity, fitness and cognitive outcomes, while others [18] reported small negative associations. Exercise has shown to improve brain processing speed by decreasing the event-related brain potential P300 in healthy subjects with sedentary lifestyles [19]. Brain imaging studies also showed that exercise improves cognitive functions by altering the efficiency of the

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neural circuitry based on functional magnetic imaging (fMRI) data, especially for overweight children [20]. The reason for these findings is that exercise benefits specific brain mechanisms, particularly the hippocampus, that is so vital for memory, learning and spatial orientation. Thus, fit children are able to attend to class work more effectively and their academic development is enhanced, which suggests that physical activity would, at best, make a modest contribution to academic performance. Accordingly, the purpose of this study was to investigate the relation between processing information and fitness level of active (fit) and sedentary (unfit) 7-year to 9-year-old children drawn from rural and urban areas in Botswana.

II. Methods

The study used cross sectional design to examine the relationship between processing information and the fitness level of active and sedentary children from urban and rural Botswana. The main design of the study included one between group factor, level of fitness (rural fit, urban fit, urban unfit), and one within group factor, task complexity (simple, choice). The dependent variables mean RT and mean MT were calculated. Level of fitness (3) x task (2) ANOVAs were calculated with the dependent variables of RT and MT. Student Neuwman-Keuls post hoc analyses were used for follow-up comparisons. Significance level for all analyses was set at $p<0.05$. Therefore, the first analysis was to determine if the subjects differed on fitness level. Group (urban fit and unfit, rural fit) x Gender ANOVA's were calculated using the resting heart rate, body weight, and BMI as dependent measures.

A. Participants

Initial screening of students (N=76) included assessment for coordination problems and experience with bicycle riding. With the help of the classroom and physical education teachers, 76 (urban) subjects aged 7-9 years were screened using the Movement Assessment Battery for Children (Movement ABC) checklist [21], to rule out Developmental Coordination Disorder (DCD). The classroom and the PE teacher completed the Movement ABC checklist for all the children. None of the subjects demonstrated any movement problem. Subjects that played video games more than one hour per week for the last year or two hours per week in the last six months were eliminated from the study. Sixteen urban subjects were eliminated due to extensive video game play. Subjects also needed to have basic knowledge of riding a bike to be eligible for the study.

Sixty consent forms along with a letter of explanation were sent to parents of urban children and 43 forms were returned. All 43 children were given a cycle ergometer exercise test. The top 15 children receiving the highest fitness scores were selected for the urban fit group (8 males,7 females) children and the fifteen with the lowest scores were selected for the urban unfit group (5 males, 10 females), the middle 13 were dropped, remaining with fit and unfit children.

For the identification of the rural children, the PE teachers selected 16 rural children they thought were the most fit based on their lifestyle and virtue of being rural area dwellers. The classroom and the PE teacher completed the Movement ABC checklist for the rural children as well. One child was dropped from the study because she had problems riding the bicycle. The remaining 15 children were selected for the rural fit group (8 males, 7 females). The experimental protocol to use children as research subjects was approved by the University of Pittsburgh's Institutional Review Board as well as the Office of the President in Botswana.

B. Tests

Assessments used in the study included anthropometric measures, cardiovascular fitness measures and cognitive assessment.

Anthropometric Measures. The height (cm) and body weight (kg) were determined using a Detecto-medic scale with an attached stadiometer. Body fat percentage was measured using bioelectrical impedance (Tanita TBF-305. The instrument was calibrated for 'child' and appropriate gender selected. The height of the subject was entered into the unit and subject was asked to step on the scale and remain motionless for 15 seconds. The unit displayed a reading of the subject's weight in pounds and fat percentage.

C. Cardiovascular Fitness Measures

Physical Work Capacity Cycle Ergometer Test. The Monark Cycle ergometer (Model 824E) was used to assess cardio fitness. Since subjects were children, the cycle was set to an initial load of 0.25 kg with a pedal rate of 60 rev/min. The termination of cycling was when the subject reached a heart rate of 150 b/min. Before the test was initiated, a polar heart rate monitor, children's size (Model CE 0537) was attached to the subject's chest to record the heart rate at 1-minute intervals. Prior to test initiation, the subject was asked to mount the bike and the height of the seat was adjusted according to the subject's leg length (95% of leg length) such that the ball of the foot was on the pedal and the knee slightly flexed.

The test began with a 2-minute warm-up to orient the subject to the equipment and prepare for the first stage. The subject was told to pedal such that every pedal revolution corresponded to the light/sound from the metronome placed on a table in front of the subject as well as a Children's OMNI scale of perceived exertion ratings chart to indicate level of fatigue [22]. At the end of the stage and prior to initiation of the next stage, the resistance increase was communicated to the subject. The exercise intensity was increased gradually through the stages of the test. Work increments used resistance of 0.5, 1, 1.5, 2, 2.5, 3, 3.5, etc. The test continued until the subject's heart rate reached 150 b/min or the subject requested the test to be stopped due to fatigue. None of the subjects discontinued the test.

To estimate power output (PO_{195}) and Maximal Oxygen Uptake (VO^2_{195}) a linear regression equation was calculated for each subject. ACSM's metabolic equation was used to calculate the Absolute VO^2. Resistance x 2 (constant) x 60 (rev/min) x 2.33 (pedal distance) + (2 x PO)+300 (body weight + 3.5 resting HR). To find the relative VO^2, the Absolute VO^2 was divided by the subject's body weight.

D. Cognitive Measures

Simple/Choice Reaction Time. The SRT task required the subject to respond as quickly as possible to the illumination of a single light while the CRT task required the subject to correctly differentiate and respond to one of three stimulus lights. The simple/choice reaction time board consisted of two components, the response board and the movement signal board. The home key was centered 20 cm from the edge of the home key board. Three response keys were located 30 cm from the home key. The signal board was 80 cm wide and 40 cm long and positioned vertically to the reaction time board. Four lights were positioned on the board. The warning light (yellow) was centered on the board 10 cm from the top. Three response lights were located 20 cm from the base of the board and equally separated by 20 cm. The color of the lights, starting from the left, was green, blue, and orange. Both boards are connected to a computer and computer controlled.

The subject placed the index finger of their right hand on the home key. Pressing the home key illuminated the warning light; this signaled the start of a random fore-period of 500 to 1500 m/sec whereby one of three response lights would illuminate signaling task initiation. The subject would then push the button signaled by the light as quickly as possible and return to the home key. The green light (left) signaled the left button, the blue light signaled the middle button and the orange light signaled the right button. For the SRT task, the warning light preceded the illumination of the blue light. For the CRT task, the three lights lit up in random order forcing the subject to make a quick decision. The computer recorded the response time to stimulus light (RT) and movement time to task light (MT).

For SRT, the subject received three practice trials followed by 15 measurement trials, while the CRT task, the subject received three practice trials followed by 45 randomly ordered trials to each of the three keys (15 trials for each key). For each trial, the reaction time and movement time was recorded. The computer automatically rejected incorrect choices and the subject repeated the trial. The trial was repeated at the end of the series of trials and an error recorded. A reaction time longer than 650 m/sec was considered an attention error and repeated at the end of the series of trials. After each trial the subject was told whether they reacted faster or slower and moved quicker and slower than the last trial.

E. Results

The means and standard deviations (SD) averaged across groups for Fat%, Height, Weight, Resting Heart Rate (RHR), Exercise Time (ET), Distance and relative PO_{150}, relative PO_{195}, relative $VO^2{}_{150}$, relative $VO^2{}_{195}$, are presented in Table I. Only significant results are discussed in the text. The between group ANOVA summary table for Resting Heart (RHR), Body Weight (BW), Body Mass Index (BMI), Exercise Time (ET), PO_{150}, PO_{195}, $VO^2{}_{150}$, $VO^2{}_{195}$, are in Table II.

TABLE I
MEANS AND STANDARD DEVIATIONS OF PHYSIOLOGICAL MEASURES, FAT%, HEIGHT, WEIGHT, RESTING H/R, EXERCISE TIME, DISTANCE AND BMI

Group		Fat%	Height (cm)	Weight (kg)	RHR (bpm)	ET (min)	Dist. (meter)	BMI (kg)
	N	15	15	15	15	15	15	15
RF	**Mean**	10.22	133.00	26.66	89.93	11.33	400	15.06
	SD	3.13	6.30	3.37	10.85	1.63	21.50	1.45
UF	**Mean**	16.04	127.00	31.26	100.53	8.53	1100	19.40
	SD	4.59	5.16	7.63	15.85	1.40	19.45	4.54
UU	**Mean**	15.61	120.60	32.26	106.53	5.33	670	21.52
	SD	5.93	6.97	26.47	15.85	0.97	15.87	13.37

F. Overall Gender Differences

Since the groups did not have equal gender representation, Group by Gender ANOVAs were calculated to test gender differences for the physiological dependable variables of Height, Weight, BMI, ET, PO_{150}, Fat%, CRT, SRT and RHR. Gender differences existed for Fat% $\underline{F}$ (1.39) = 36.36 (p = 0.00), ET, $\underline{F}$ (1.39) =8.83 (p = 0.00), PO_{150}, $\underline{F}$ (1,39) = 12.84 (p = 0.00), RHR $\underline{F}$ (1.39) = 5.00 (p = 0.03). Females had higher Fat% (Mean = 17.03 SD 4.9) than males (Mean = 10.74, SD = 3.5). Males exercised the longer (Mean = 9.00 min, SD = 2.52 min) than females (Mean = 7.8 min, SD =2.53 min). Females had higher RHR (Mean = 103.47 bpm, SD = 14.82 bpm) than males (Mean = 94.31 bpm, SD= 15.47 bpm) and also had lower PO_{150} (Mean = 143.05 kg/min, SD = 34.93 kg/min) than males (Mean = 255.52 kg/min, SD = 90.71 kg/min).

Body Weight. There were no significant differences in body weight among the three groups, $\underline{F}$ (2.42) = 0.52 (p = 0.60). However, the variability in the UU group was high (SD = 26.47kg) compared to the UF (7.63 kg) and RF (3.37 kg) groups suggesting greater within group variability in weight for the UU group. The range of weight for the unfit group was from 18.0 kg to 53.0 kg. There were no significant differences in BMI between the three groups, $\underline{F}$ (2.39) = 1.39 (p = 0.24). There variability within the UU group was higher (SD = 13.37kg) compared to the RF group (SD = 1.45 kg) and the UF group (SD = 4.45kg) (Table I).

Resting Heart Rate. The group main effect for RHR, was significant, $\underline{F}$ (2.42) = 6.38. A Student Neuman-Keuls follow-up test revealed no significant differences in the means between UU (Mean = 106.53 bpm, SD = 15.85 bpm) and UF (Mean 100.53 bpm, SD = 15.85 bpm); however, both groups had significantly higher heart rates than the RF (Mean = 89.93 bpm, SD = 10.85 bpm) group (Table I). There was a correlation between the groups' RHR and their fat%. The Pearson correlation Coefficient of fat% and RHR was r = 0.31 (p = 0.03). Thus, those children with groups, higher fat% also had higher RHR.

TABLE II
PHYSIOLOGICAL MEASURES

Body weight	*Source*	DF	Mean Squares	F Value	P Value
	Group	2	*133.80*	*0.52*	*0.59*
	Error	42	*256.83*		
Body Mass Index	*Source*	DF			
	Group	2	*111.25*	*1.39*	*0.24*
	Error	39	*3125.09*		
RHR	*Source*	DF			
	Group	2	*1864.80*	*6.38*	*0.00*
	Error	42	*292.34*		
Exercise Time	*Source*	DF			
	Group	2	*30.95*	*59.10*	*0.00*
	Error	42	*0.52*		
PO150	*Source*	DF			
	Group	2	*83248.84*		
	Error	42	*3430.75*	*24.27*	*0.00*
PO195	*Source*	DF			
	Group	2	*421390.58*	*21.17*	*0.00*
	Error	42	*19904.58*		
V02 at 150	*Source*	DF			
	Group	2	469.06	19.82	0.00
	Error	42	23.66		

TABLE III
MEANS AND STANDARD DEVIATIONS FOR PO AT 195 AND VO_2 AT 195

Group		PO_{195} (kg/min)	$VO_{2\ at\ 195}$(ml/kg/min)
RF	Mean	653.17	52.97
	SD	215.24	17.07
UF	Mean	432.81	32.30
	SD	107.20	8.93
UU	Mean	324.23	27.81
	SD	43.47	6.62

Relative Power Output at 195 bpm. A between groups analysis revealed a statistically significant PO_{195} among the three groups. The groups main effect for and PO_{195} was F (2.42) = 21.17.The Student Neuman-Keuls follow-up test indicated that all groups were significantly different. The group mean for the RF group had a higher PO_{195} (653.17 kg/min, SD = 215.24 kg/min) than the UF group, PO_{195} (432.81 kg/min, SD = 107.20 kg/min) and UU group PO_{195} (324.23 kg/min, SD = 43.47 kg/min) (Table III).

Relative VO_2 at 195 bpm. A between groups analysis revealed a statistically significant VO_2 at 195 among the three groups, VO_2 at 195 was F (2.42) = 19.51. The Student Neuman-Keuls follow-up test indicated a significant difference between the RF group and the two urban groups at VO_2 at 195. The group mean for RF had higher for relative VO_2 at 195 (52.97 ml/kg/min, SD = 17.07 ml/kg/min) than the UF VO_2 at 195 (32.30 ml/kg/min, SD = 8.93 ml/kg/min) and UU VO_2 at 195 (27.81 ml/kg/min, SD = 6.62 ml/kg/min). The UF and UU did not differ at VO_2 at 195 (Table III).

G. Cognitive Function Measures

Reaction Time The only significant difference for RT was the test main effect, F (2.42) = 173.51. The group by test interaction approached significance F (2.42) = 2.36 (p = 0.11). The trend was that the RF group was faster at the simple task (287.00 m/sec, SD = 52.73 m/sec) than UF (322.19 m/sec SD = 40.39 m/sec) and UU (313.20 m/sec SD = 34.35 m/sec) who did not differ at the SRT level.

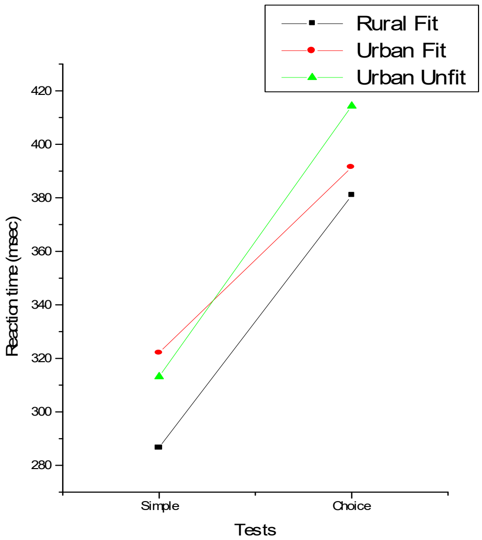

Fig. 1 Fitness group effects for SRT and CRT

The RF group was also faster for the choice task (381.00 m/sec, SD = 64.68 m/sec) than UU (414.36 m/sec, SD = 30.98 m/sec) but not different from UF (392.00 m/sec SD = 41.43 m/sec) (Fig. 1).

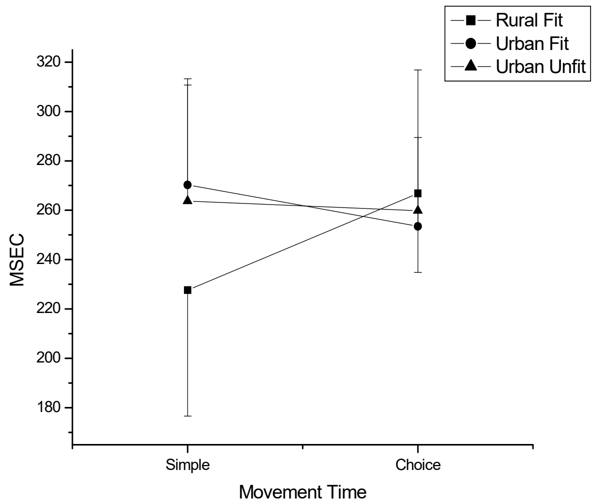

Fig. 2 Group effect and Test for MT

Movement Time. The main effects of group and test for MT were not significant, F (2.42) = 0.93 (p = 0.34) and F (2.42) = 0.93 (p = 0.34). The group by test interaction was significant for MT F (2.42) = 7.01 (p = 0.00). The Fisher's least significant difference indicated that the RF group was faster at simple task (228.00 m/sec, SD = 50.75 m/sec) than UF group (270.28 m/sec, SD = 31.65 m/sec) and UU group (264 m/sec, SD = 46.65 m/sec) but did not differ for the more complex task (267.00 m/sec, SD =57.14 m/sec) with the UF group (253.49 m/sec, SD = 43.17 m/sec) and UU group (260.00 m/sec, SD = 35.75 m/sec) (see Fig. 2). A possible reason could be that the UF group, by virtue of being fitter than UU group performed well in complex tasks when compared with UU group and did not differ with RF group.

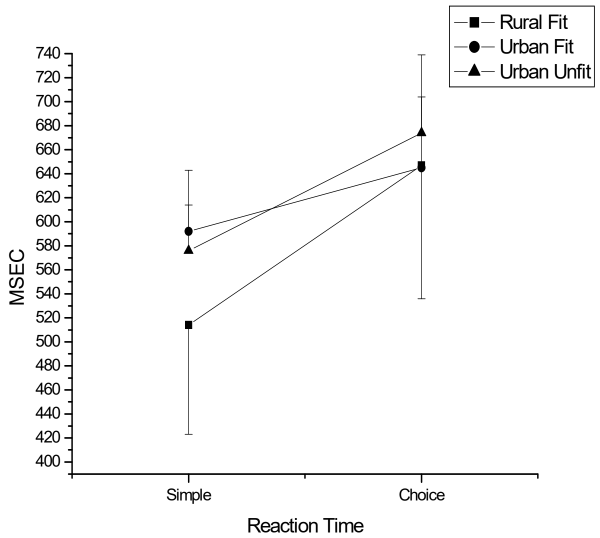

Fig. 3 Group effect and test for RT

III. Discussion

The primary purpose of the study was to investigate the relationship between physical fitness and cognitive function of children aged 7-9-years drawn from urban and rural areas of Botswana. The study examined the information processing and fitness level of active (fit) and sedentary (unfit) children, their fitness level, and the speed at which they process information and make decisions. This was done by first testing children's fitness level, categorizing them according to their level of fitness, and then testing them using simple and choice reaction time paradigms. It was proposed that children with a sedentary (unfit) lifestyle from an urban area, selected based upon their fitness tests, would show greater variability by responding more slowly on CRT tasks when compared with fit children of the same age group from a rural area. It was also proposed that there would be limited difference between fit and less fit children on SRT tests, since the task is not as complex as CRT.

It was hypothesized that children from rural areas in Botswana, due to physical activity embedded in their lifestyle, would perform better in physical fitness tests than their counterparts in urban areas. The results of the fitness testing tasks supported the selection hypothesis of the subjects, since the groups were different on the physiological tests. The RF group had superior performance on cardio-respiratory fitness tests by achieving higher physiologic functional capacity and power output (PO_{150} and VO_2 at 195) when compared with their counterparts in the urban area. The UF group also showed superior performance over the UU group on the same measures. The RF group weighed similar to the urban groups, but had lower RHR, Fat%, BMI and exercise the longest. The UU group weighed the most, had higher percentage fat, BMI, and the highest RHR. The heavier weight amongst urban children was also found in the study by Collert & Mokgwathi [23], which was attributed to nutritional differences. The differences in observations indicated that the RF group exercised the longest, followed by the UF group and the UU group with the least exercise time.

The results reported in this study are similar to those by Washington et al. [24], which reported aerobic and anaerobic exercise data for North American school-age children; Botswana and North America children had almost the same average weight of 30 kg and 33 kg, respectively, and the RHR was also at 98.99 b/min and 99.16 b/min. However, the body weight of American children ranged from 29 kg to 67 kg, while Botswana children ranged between 22 kg and 35 kg. Other variables such as Vo_2 could not be compared, as this study calculated Vo_2 at 150 b/min while Washington's study used a different protocol, the same was with exercise time. All these results do not agree with those of Hamilton & Andrew [25] which reported that children are regarded as fit and maximally trained by their own habitual exercise of play therefore exercise is not necessary. Thus, exercise has become an important part of everyone's life; given the sedentary and westernized lifestyle we lead today.

The hypothesis that children with a sedentary (unfit) lifestyle from an urban area, selected based upon their fitness tests, would show greater variability by responding more slowly on CRT tasks when compared with fit children of the same age group from a rural area, was not clearly supported in the study but the data demonstrated a trend. For the SRT task, the RF group was faster than UU and UF groups. The RF group was also faster at CRT than the UU group; however, they did not differ with the UF group. The analysis of MT revealed that the RF group showed superior performance on MT as well. They were faster at simple task than the UF and the UU groups, but not different from UF group at the choice task. This trend is in agreement with studies [3], [16], [13] of children that active (fit) subjects demonstrate faster reaction and movement times on cognitive measures than low active ones, and that reported aerobic exercise accelerated reaction time compared with the rest condition.

Key findings of this study are consistent with the findings of the Bluma & Lipowska [26] study that physical activity may be associated with changes to certain brain structures, leading to an improvement in the speed of processing information, as well as cognitive control. A possible explanation for the interaction on MT for the choice task maybe based on an environmental influence, the urban children might have matched rural children because of their exposure to traffic lights, TV games, a complex urban life and other interactive gadgets found in urban areas. On the other hand, the RF group's superior performance at SRT level may be hereditary; the people who live in the rural areas marry within the same region, and their muscle recruitment is shaped by the environmental demands (hunting, running, avoiding danger), and might be responsible for their quick reaction.

The implication of the trend in the results is that aerobic fitness per se, appears to be a factor of moderate importance in cognitive functioning. One basic rationale that may be constructed to explain the fast central processing time of these physically active children from rural areas, though circumstantial, involves the cerebral circulation hypothesis [3], [9], [17], where physical activity is thought to increase brain blood flow, which in turn benefits the cognitive functioning of the organism, due to increased supply of nutrients to the brain (glucose and oxygen). These rationales, which indicate a life-giving function of a healthy cardiovascular system, suggest that the central nervous system circulation of these active children maintains an optimal processing efficiency.

In sum, physical fitness could be a factor in maintenance of speed at which we process information, including decision-making. Furthermore, maintaining a physically active lifestyle is of paramount importance not only to our health, but to our cognitive function as well.

The study had its own limitations, the sample size was small, and that clearly limited the generalizability of the study. It is necessary for future research to examine if the benefits of physical fitness are general in nature or specific to certain types of cognitive functioning, as this study used the simple and choice paradigm only. There is a need to conduct a longitudinal study to determine if the outcomes of this study were not in any way affected by the maturational stage of the participants. Furthermore, future studies could take those children considered or identified as unfit, subject them to a training intervention and then test them to establish if their cognitive function will improve post training.

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