LONGITUDINAL CHANGES IN ENERGY EXPENDITURE IN CHILDREN AND ADOLESCENTS

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ABSTRACT

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This dissertation contains an introduction chapter (Chapter 1), a review of the literature (Chapter 2), two manuscripts (Chapters 3 and 4) and a summary chapter (Chapter 5). The first manuscript is a mixed longitudinal study that examined change in walking and running economy over four years in children and adolescents. The second manuscript is a mixed longitudinal study that examined change in energy expenditure in four lifestyle physical activities (dance aerobics, laundry, basketball, and sweeping) over four years in children and adolescents.

To examine change in economy and energy expenditure, VO_2 was expressed in both absolute (L/min) and relative terms (ml/kg/min). Change in VO_2 over time in youth is traditionally expressed in relative terms. However, by expressing VO_2 in absolute terms while using weight as a covariate in the analyses, the purpose was to obtain results comparable to those used with ratio scaling of VO_2. However, this was not the case and the data did not fit the hierarchical linear model for the six activities when VO_2 was expressed in L/min.

Similar to previous literature, relative VO_2 (ml/kg/min) decreased over time for walking and running in children and adolescents. Relative VO_2 also decreased over time in the four lifestyle activities, which is a new contribution to the literature. Factors found to influence change in relative VO_2 over time included: body surface area (laundry, sweeping, walking), chronological age (aerobics, laundry, sweeping,

walking), leg length (running, walking), and ventilation (aerobics, basketball, laundry, sweeping, walking).

For laundry and sweeping (VO_2 ml/kg/min), the predictor variables (body surface area, chronological age, and ventilation) explained all of the variance in slope; meaning individual variation in change in VO_2 over time was explained. For walking, running, basketball, and aerobics, slope was still significant in the final model. In conclusion, relative VO_2 for six different physical activities decreases over time in children and adolescents and is explained by a variety of factors depending on the activity. Other factors not included in this study should be examined to further explain the individual variation in slope in these activities.

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CHAPTER 1

INTRODUCTION

In exercise science, economy is defined as the aerobic demand or energy cost required to perform a submaximal exercise task[1]. Studying the change in economy from childhood through adolescence is important because it addresses differences in energy expenditure during various activities and thus influences ability to accurately predict energy expenditure in this population. This is important as it relates to the Compendium of physical activities for children and adolescents. As more measurement tools are developed to quantify habitual physical activity, it is important to understand how VO_2 changes over time in this population so that accurate methods for estimating energy expenditure can be developed. Understanding change in economy over time in children and adolescents is also important as it may influence performance in different sports (i.e. running performance). Previous studies, both cross-sectional and longitudinal, have shown children are significantly less economical (i.e., have higher energy cost) when walking and running than adults[1-5]. Children (6 to 12 years old) are also less economical compared to adolescents (13-18 years old)[6]. Much of this previous research focused on laboratory based treadmill walking and running. It is unknown whether differences in economy exist between children and adolescents or adults during performance of lifestyle activities that are less locomotor-based such as laundry, aerobics, basketball and sweeping.

Several factors have been suggested to contribute to children being less economical than adolescents and adults. These factors include age[2, 3], resting metabolic rate[7, 8], body size[1], gender[9], substrate utilization[10], biomechanics[11, 12], training[13], ventilation[2], and maturation[14]. While there are suggestions to support each factor and its influence on the difference in walking and running economy between children and adults, one single factor does not definitively explain why this difference occurs. Hence, it is considered to be multi-factorial. Of all the factors thought to influence economy, body size has been the one most studied. Rowland et al. compared submaximal VO_2 between children and adults while running[2, 3] and found that when VO_2 was expressed relative to body surface area, the difference in submaximal VO_2 between children and adults was no longer significant[2, 3]. In attempt to account for the differences in economy due to body size, Allor et al. matched girls and women for weight and height[4]. The authors found that the girls had a significantly higher submaximal VO_2 during both walking and running compared to women even though the groups were matched for body size[4]. The difference in running economy between girls and women in the study by Allor[4] et al. was less than that found by Rowland[3] who did not match groups based on size. This indicates that body size (height, weight) explains some, but not all of the variance in economy between children and adults.

Unnithan and Eston found stride frequency influences running economy in children compared to adults[2, 11]. Children have a greater stride frequency than adults, suggesting that the increased muscle contraction results in a greater oxygen demand during submaximal exercise in children[11]. At three different running speeds, Rowland et al. found the ratio of VO_2 to stride frequency for boys was 0.46, 0.51, and 0.53 and for men 0.48, 0.51, and 0.54[2]. The similarity in VO_2 to stride frequency between the boys and men suggests that stride frequency plays a major role in the difference between running economy in boys and men[2].

Results on the influences of gender, resting metabolic rate (RMR), percent body fat, leg length, and ventilation on economy are inconclusive. In some studies, girls were found to be more economical than boys[5, 9, 15, 16]. Other studies have failed to find a gender difference[8, 17-19]. For RMR, MacDougall et al. found age to be inversely related to resting metabolic rate in participants 7-37 years old[8]. However, the difference over this age range was small at 1-2 ml/kg/min which may explain some of the difference in economy but not all[8]. Children also have increased minute ventilation (L/min) during exercise compared to adults[2, 4] which may result in a greater energy cost from ventilation. Differences in ventilation between children and adults, although small, may explain some of the variation in submaximal VO_2. Leg length has only been previously examined when included as a ratio with stride length (SF/LL) or setting treadmill speed to a relative intensity (3.71 leg lengths per second)[1], so the impact of leg length on economy is unknown. Percent body fat is rarely included as a factor related to economy. Ayub et al. found no difference in VO_2 (ml/kg/min) between lean and obese boys during exercise[20]. Further research is needed to determine the extent to which these factors influence changes in economy over time in children and adolescents.

Additionally, maturity status is thought to contribute to economy; however research in this area is very limited[21]. While maturity status is thought to influence economy, mixed results have been found. This could be due, at least partially, to differences in the various methods have been used, to assess maturity status, making comparisons across studies difficult. Armstrong et al. found no difference in VO_2 during running in 12-year old boys and girls grouped by maturation status[21]. However, Spencer et al. found when matched for chronological age (10-14 years old), late maturing boys had better running economy compared to early maturing boys[14]. Armstrong et al. used pubic hair development according to Tanner's criteria to determine maturity status, while Spencer et al. used age at peak height velocity (APHV). Differences in methods used for determining maturity status may explain the differences in results. Due to the limited data available, it is unclear whether maturity status influences economy.

The majority of research examining economy has been limited to cross-sectional studies comparing economy between children and adults or children grouped by age. While a cross-sectional study design provides insight into differences between groups, it does not allow for examination of changes that occur over time within a given individual. In children, the use of a longitudinal study design is particularly valuable, as it allows growth and maturation to be taken into account over an extended period of time. A limited number (n=5) of longitudinal studies have been conducted on changes in walking and running economy of children and adolescents[5, 13, 22-24]. Morgan et al. found VO_2 to be 27% higher during treadmill walking when children were six compared to 10 years old[23]. In this study, participants walked at six different speeds, and the decrease in VO_2 was more pronounced from six to eight years old than at later ages[23]. Ariens et al. found submaximal VO_2 decreased from age 13 to age 27 in males and females during running[5]. The greatest improvement in running economy was seen during adolescence, from 13 to 16 years old[5]. To our knowledge, a mixed longitudinal analysis describing the changes in walking and running economy in both children and adolescents is not available. Further, except for cycling, no information is available on changes in economy in other physical activities. Laundry, aerobics, sweeping, and basketball were examined since children participate in these activities on a regular basis. For these physical activities, participants were read a standardized script over four years. However, there was no measure to determine if they completed the activities at the same intensity each year. We, therefore, cannot refer to change in these activities as economy and will instead use energy expenditure. It is unknown whether energy expenditure improves longitudinally in lifestyle or sport-based activities that require movement in all planes. A better understanding of longitudinal changes in energy expenditure in these types of activities will help improve accuracy in predicting energy expenditure in children and adolescents.

The overall purpose of this dissertation was to examine longitudinal change in economy and energy expenditure and factors thought to influence this change during locomotor and non-locomotor physical activities. The dissertation was separated into two manuscripts. The first examined longitudinal changes in over-ground walking and over-ground running economy and factors thought to influence these changes in economy in children and adolescents 5 to 16 years old [Aim 1, Hypotheses 1 and 2, and Aim 2, Hypotheses 1 and 2]. The second manuscript examined longitudinal changes in energy expenditure during lifestyle activities (laundry task, aerobics, sweeping, and basketball) and factors thought to influence these changes in energy expenditure in the same population [Aim 1, Hypotheses 3-6, and Aim 2, Hypotheses 3-6].

Research aims and hypotheses

Aim 1: Examine changes in economy/energy expenditure expressed as absolute VO_2 (L/min) (covariates: chronological age, weight, and gender) and relative VO_2 (ml/kg/min) (covariates: chronological age and gender) during six different physical activities (over-ground walking, over-ground running, laundry task, aerobics, sweeping, and basketball (shooting and dribbling)) over four years in children and adolescents.

Hypothesis 1: Walking economy, expressed as absolute VO_2, would improve over the four years. Walking economy, expressed as relative VO_2, would improve over the four years.

Hypothesis 2: Running economy, expressed as absolute VO_2, would improve over the four years. Running economy, expressed as relative VO_2, would improve over the four years.

Hypothesis 3: Energy expenditure during the laundry task would decrease when expressed as absolute VO_2 over the four years. Energy expenditure during the laundry task would decrease when expressed as relative VO_2 over the four years.

Hypothesis 4: Energy expenditure during aerobics would decrease when expressed as absolute VO_2 over the four years. Energy expenditure during aerobics would decrease when expressed as relative VO_2 over the four years.

Hypothesis 5: Energy expenditure during sweeping would decrease when expressed as absolute VO_2 over the four years. Energy expenditure during sweeping would decrease when expressed as relative VO_2 over the four years.

Hypothesis 6: Energy expenditure during basketball would decrease when expressed as absolute VO_2 over the four years. Energy expenditure during basketball would decrease when expressed as relative VO_2 over the four years.

Aim 2: Determine predictor variables that influence the longitudinal change over four years in economy/energy expenditure expressed as absolute VO_2 (L/min) (covariates: chronological age, weight, and gender) and relative VO_2 (covariates: chronological age and gender) during six different physical activities (over-ground walking, over-ground running, laundry task, aerobics, sweeping, and basketball) in children and adolescents. Predictor variables that were to be entered into the models included: BSA, leg length, ventilation (L/min), stride frequency (walking and running only), resting energy expenditure (REE), percent body fat, and maturation.

Hypothesis 1: For both absolute VO_2 and relative VO_2, body surface area would be a significant predictor and explain the greatest amount of variance in change walking economy over the four time points. Stride frequency would also be a significant predictor of walking economy, but REE, ventilation, leg length, maturity status, and percent body fat would not be significant predictors of walking economy.

Hypothesis 2: For both absolute VO_2 and relative VO_2, body surface area would be a significant predictor and explain the greatest amount of variance in change running economy over the four time points. Stride frequency would also be a significant predictor of running economy, but REE, ventilation, leg length, maturity status, and percent body fat would not be significant predictors of running economy.

Hypothesis 3: For both absolute VO_2 and relative VO_2, body surface area would be a significant predictor and explain the greatest amount of variance in change in energy expenditure during laundry task over the four time points. REE, ventilation, leg length, maturity status, and percent body fat would not be significant predictors of economy during laundry task.

Hypothesis 4: For both absolute VO_2 and relative VO_2, body surface area would be a significant predictor and explain the greatest amount of variance in change in energy expenditure during aerobics over the four time points. REE, ventilation, leg length, maturity status, and percent body fat would not be significant predictors of economy during aerobics.

Hypothesis 5: For both absolute VO_2 and relative VO_2, body surface area would be a significant predictor and explain the greatest amount of variance in change in energy expenditure during sweeping over the four time points. REE, ventilation, leg length, maturity status, and percent body fat would not be significant predictors of economy during sweeping.

Hypothesis 6: For both absolute VO_2 and relative VO_2, body surface area would be a significant predictor and explain the greatest amount of variance in change in energy expenditure during basketball over the four time points. REE, ventilation, leg length, maturity status, and percent body fat would not be significant predictors of economy during basketball.

CHAPTER 2

REVIEW OF LITERATURE

Introduction

Economy is defined as the aerobic demand or energy cost required to perform a submaximal exercise task[1]. A lower VO_2 (ml/kg/min) when performing a given activity is considered as more economical. Physical activities such as walking and running have been used to study differences in economy among children, adolescents, and adults. Numerous cross-sectional and longitudinal studies have found that children are less economical than adults during walking and running[2, 3, 22, 23]. Many factors have been suggested for why there is a difference in economy between children and adults including age, gender, maturation, resting metabolic rate, body size, stride frequency, stride length, and leg length, substrate utilization, ventilation, percent body fat, and other factors (training, running mechanics). Each of these factors will be discussed in the following text.

Economy can be used as a measure of performance in endurance events. Performance in these types of events, such as long distance running, is influenced by the amount of oxygen used by the working muscles and by the energy cost or VO_2 at submaximal workloads (economy)[25]. Absolute maximal VO_{2max} (L/min) increases during childhood and adolescence due to an increase in body size[26]. When VO_{2max} is expressed relative to body weight, it stays relatively stable during childhood and adolescence and into adulthood in males and shows a slight decline in girls due to an increase in fat mass during puberty[27]. Therefore, when comparing a child to an adult during submaximal exercise, adults use a smaller percentage of their VO_{2max}

than do children when walking or running at a given speed. Improvements in distance running events indicated by a decrease in performance time are generally seen throughout childhood and into adolescence[24]. Given the similar relative VO_{2max} values between children and adults, especially in males, this suggests that children have a capable and effective aerobic capacity to meet the demands of exercise[2]. However, Astrand proposed that inferior economy prevents younger boys from running as well during a distance event compared to older boys who had a similar VO_{2max}[28]. The purpose of this literature review is to discuss factors thought to influence economy in children and adolescents. A second purpose is to discuss previous longitudinal studies on economy in children and adolescents and the potential influence of growth and maturation on economy. The first section of this review describes evidence from both cross-sectional and longitudinal studies regarding factors related to economy. The next section describes specific details of longitudinal studies, followed by a section on normalizing VO_2, and concludes with a section on economy in non-locomotor activities.

Factors affecting economy

Age

Economy improves with age in children during both walking and running and in boys and girls. In a cross-sectional study, Rowland et al. found boys had a higher submaximal VO_2 while running compared to men (49.5±4.4 vs. 40.0±5.0)[2]. Similar results were found in girls. Girls were found to have a higher VO_2 during walking and at two different running speeds compared to women[3]. In this study, the difference in economy increased with speed and became significant during running ($p<0.05$)[3]. Unnithan and Eston found that boys (10.4±0.5 years old) had a higher submaximal VO_2 (ml/kg/min) at four different running speeds compared to men (20.8±1.2 years old)[11]. Based on results from these studies, age appears to explain some, but not all, of the variance in economy between children and adults.

Differences in economy also exist between children and adolescents. Astrand found that when both boys and girls ran on a treadmill at three different speeds, the younger subjects (4-6 years old) had a higher VO_2 compared to the older subjects (16-18 years old)[28]. Astrand concluded that there is a positive linear relationship between VO2 and speed and that younger subjects have a higher VO_2 at all speeds[28]. Waters et al. found that when children were asked to walk around an outdoor track at their own comfortable walking speed, children 6-12 yrs old had a significantly greater VO_2 (15.3 ml/kg/min) than adolescents 13-18 yrs old (12.9 ml/kg/min)[6]. Results from these studies suggest that children have a lower economy compared to adolescents.

All previously mentioned studies have been cross-sectional while the ideal design to show change in economy with age would be a longitudinal. Few longitudinal studies have been conducted on economy. However, those that exist have shown similar results to cross-sectional studies. An early longitudinal study conducted on economy related to age used data from The Amsterdam Growth and Health Study (AGHS). The AGHS was a longitudinal study that began in 1977 with the overall purpose of studying growth, fitness, and health of males and females from adolescence to adulthood. Ariens et al. reported on the longitudinal changes in running economy in both males and females from age 13-27 years old[5]. In this study, participants (182 participants; 84 males and 98 females) were measured at six different time points. The first four measurements occurred annually from age 13-16[5]. The last two measurements were taken during adulthood when participants were 21 and 26 years old. They found that there was a significant decrease in VO_2 during submaximal running from 13-27 years old in both males and females at different three grades (0%, 2.5%, and 5%) at the same speed (8km/hr). The greatest improvement in running economy was seen during adolescence with a 5ml/kg/min decrease in VO_2 occurring from age 13 to 16. From age 16 to 27, there was only a 2ml/kg/min decrease in VO_2. One limitation to this study is that each stage was only two minutes in duration. In order to obtain an accurate measure of submaximal VO_2, steady state must be achieved. In adults, it takes approximately three to four minutes to reach steady state depending on exercise intensity[29]. The authors concluded that due to the length of each stage, steady-state exercise intensity may not have been achieved, as VO_2 may still have been increasing when measurements were taken[5].

In another longitudinal study, Morgan et al. used data from the Locomotor Energy and Growth Study (LEGS) to examine changes in VO_2 related to physical growth in children[23]. In this study, the authors measured VO_2 during walking in 23 children from age six to ten years over six different speeds. VO_2 averaged across the six speeds was 27% higher in the six year olds compared to the ten year olds[23]. The decrease in VO_2 was more pronounced from six to eight years old, as it decreased significantly for all six speeds. While VO_2 continued to decrease from age eight to ten, the decline was smaller in magnitude and for some speeds did not change at all. The authors also compared the VO_2 values from the six year olds versus values from an adult population[30]. They found VO_2 was 44% higher in children six years old than in the adults. The authors only speculate as to why these differences in walking economy occurred, including differences in body size, substrate utilization, and immature biomechanics.

It is interesting to note that while economy improves with age, children who have better economy than their peers tend to maintain their ranking over time and vice versa. Morgan et al. found that walking and running economy rank was relatively stable over the five-year period[22]. Using yearly change in VO_2 for both walking and running over the five-year period, they found that 85% moved six or less positions in rank, 61% (running) and 64% (walking) moved four or fewer positions, and 27% of participants moved two or less positions (n=23)[22]. These results infer that if a child has poor walking economy at age 6, s/he will continue to have poor economy at age 10. Similar results were found by Krahenbuhl et al. who found that participants (n=6), who performed a submaximal running VO_2 test at age 10 and 17, maintained a relatively stable rank position[24]. Three participants did not change their ranking and a fourth subject only moved one position. Based on the work by Morgan[22] and Krahenbuhl[24], although it has been shown that economy improves with age in youth, a given child's relative position within a group remains relatively stable over time.

Gender

Results from studies examining gender differences in walking and running economy in children and adolescents are inconclusive. Some studies showed girls to be more economical than boys[5, 9, 15, 16] while others have failed to find a difference[8, 17-19]. To the author's knowledge no study has found boys to be more economical than girls.

A difference in walking economy between genders was found in pre-pubescent children. Freedson et al. found that girls were more economical than boys at three walking speeds (67, 94, and 127.5 m/min)[9]. The difference in VO_2 at each of the three speeds between boys and girls was small (~3-5ml/kg/min) and caution should be used when interpreting these results due to the small sample size (8 participants: 4 girls and 4 boys). Similar results were found by Morgan et al. who found six year old girls to be more economical than 6 year old boys when running on a treadmill at 5 mph for 5 minutes[15]. Girls were more economical when expressed as Gross VO_2 (39.1±2.8 vs. 36.5±2.9) and Net (Gross-Resting) VO_2 (31.1±2.8 vs. 28.9±2.5). However, differences disappeared when VO_2 was expressed relative to fat-free mass (46.9±3.4 vs. 44.8±4.0 ml/kg FFM/min)[15].

In a longitudinal study, Ariens et al. found girls from age 13 to 17 to be more economical while running compared to boys of the same age[5]. The difference in running economy was seen at 8km/h at a slope of 0% and 2.5% grade. While statistically significant, the difference in VO_2 was small, ~1-2ml/kg/min indicating gender may not influence economy, since daily variation for VO2 collected via indirect calorimetry is ~2 ml/kg/min[31].

Overall, it is difficult to conclude whether there is a difference in economy between genders. In studies where a difference in economy has been found, the difference in VO_2 is small (~1-5 ml/kg/min). Therefore, while statistically significant, these small differences in VO_2 may not have practical significance.

Maturation

Maturity status is thought to contribute to economy[14]. However research in this area is very limited. Maturity status can be determined by a number of different methods including stages of sexual maturation developed by Tanner, skeletal age, or age at peak height velocity. In general, studies examining changes in economy in children and adolescents group participants by age and ignore maturity status.

Of the studies that have examined the effects of maturation on economy, the results are equivocal. In a cross-sectional study, Segers et al examined running economy in boys who played soccer grouped by maturity status[32]. Maturity status was determined by skeletal age using the Tanner-Whitehouse method. No difference in running economy was found between early and late maturing boys[32]. A longitudinal study by Welsman and Armstrong examined changes in submaximal VO_2 related to age, gender, and maturation[33]. Participants (n=236, 118 boys and 118 girls) were measured annually from age 11 to 13. They completed an incremental running test on a treadmill and submaximal VO_2 was measured at 8km/h. Maturity status was determined by pubic hair development using stages developed by Tanner. In this study, maturity status was found to have no effect on submaximal VO_2. They instead found skinfold thickness and body mass to have the greatest influence[33]. Findings by Welsman and Armstrong support those found by the same research group, that maturity status does not influence submaximal VO_2 in children[21].

One study has found maturity status to influence running economy. Spencer et al. used data from the Saskatchewan Growth and Development Study[14]. In this study, maturation was assessed by age at peak height velocity. The authors found that late maturing boys from 10-14 years old had better running economy compared to early maturing boys when matched for chronological age. At age 12 and 13, average maturing boys were found to be more economical than early maturers[14]. Spencer et al. expressed VO_2 relative to body surface area while Welsman and Armstrong and Segers et al. used allometric scaling. The difference in how energy expenditure was expressed could explain some, or all, of the results. With such limited data available on the influence of maturation on economy and with maturity status assessed by different methods, it is difficult to draw many conclusions in this area.

Resting energy expenditure

When expressed relative to body weight, basal metabolic rate (BMR) declines with age in both boys and girls[34]. In a cross-sectional study, Garn and Clark found BMR expressed per kilogram body weight decreased from age 6 to 17 in boys and girls[35]. Basal metabolic rate is difficult to measure, and generally requires a participant to spend the night at the laboratory, which increases subject burden. As a result, resting energy expenditure (REE), which can be obtained from a metabolic cart in approximately one hour, is more commonly used.

Bar-Or pronounced that differences in resting energy expenditure between adults and children are approximately 1-2 ml/kg/min[7]. Martinez et al. found girls have a significantly higher RMR compared to women but the difference was only ~1.5ml/kg/min supporting Bar-Or[10]. When matched for body size, girls had a higher RMR compared to women but the difference was not statistically significant (4.4±0.8 vs. 3.9±0.5 ml/kg/min)[4]. Allor et al. measured pre-exercise REE in women and girls matched for height and weight[4]. They found no difference in pre-exercise REE between groups (4.4±0.8 vs. 3.9±0.5 ml/kg/min)[4]. The difference in RMR between children and adults may explain some of the difference in economy but not all.

Body size

Heat production and oxygen consumption relative to body weight are higher in smaller animals compared to large animals[36]. Due to a greater body surface area to mass ratio, smaller animals need to generate more heat to account for additional heat loss. This is referred to as the Surface Law or Surface Rule. The Surface Law applies to different species as well as growth and maturation within a single species[2]. Therefore, children have a greater body surface area to mass ratio compared to adults and thus a greater oxygen consumption and heat production, which can be seen in differences in REE.

With respect to the Surface Law, economy should improve throughout childhood into adolescence and adulthood until an individual reaches his or her adult body size. As previously mentioned, a number of studies have found that children have an inferior walking and running economy compared to adults[2, 3]. Rowland et al. further found that when VO_2 was expressed relative to body surface area, the difference in running economy was no longer significant, supporting the Surface Law as a major factor regarding differences in running economy[2, 3]. However, Maliszewski and Freedson found that when boys and men ran at the same absolute running speed (9.6kph), energy expenditure expressed relative to BSA was 13% higher in the men than boys. The authors suggested that this difference was due to the men having a greater relative amount of muscle compared to the boys.

In attempt to account for the differences in economy due to body size, Allor et al. compared girls and women matched for height and weight during submaximal walking and running[4]. The authors hypothesized that since the girls and women were matched for body size, no difference in VO_2 would be found between the two groups. The girls were found to have a higher VO_2 (lower economy) than the women for both walking (16.4±1.7 vs. 14.4±1.1 ml/kg/min) and running (38.1±3.7 vs. 33.9±2.4 ml/kg/min)[4]. In this study, a similar protocol to that of Rowland[3] was used. Girls in the Rowland study were not matched for height or weight and were shorter and weighed less than the women. Rowland et al. found no difference in walking economy but the girls had a significantly higher VO_2 for running[3]. In contrast, Grossner et al. found no difference in submaximal VO_2 between girls and women matched for body size when walking and running at three different speeds[37]. Based on these results, it appears that matching girls and women for body size (height and weight) explains some, but not all, of the difference in running economy between the two groups.

Stride frequency, stride length, and leg length

Differences in running technique are thought to contribute to children having a higher submaximal VO_2 compared to adults. A number of different reasons have been proposed with stride frequency, stride length, and leg length the most commonly studied. Children have a higher stride frequency than adults when running at a given speed on a treadmill[2, 11]. Rowland et al. found the ratio of VO_2 to stride frequency for the boys was 0.46, 0.51, and 0.53 and 0.48, 0.51, and 0.54 in the adults at the three different submaximal speeds[2]. Unnithan and Eston found similar results[11]. Maliszewski and Freedson found that stride frequency was higher in boys compared to men at an absolute (9.6kph) and relative (3.71 leg lengths per second) running speed[1]. Results from these studies indicate that children and adults have a similar VO_2 cost per stride. Since children have a greater stride frequency than adults, the increased stride frequency results in a greater oxygen demand during submaximal exercise in the children[11].

When running, individuals typically select an optimal stride frequency to stride length ratio that is the most economical[38]. Stride length was found to be greater in adults compared to children[1, 11] with children compensating for this difference by increasing stride frequency as previously noted. Rowland et al. found that the optimal stride frequency to stride length (SF/SL) was higher in boys compared to men[2]. Maliszewski and Freedson found the SF/SL ratio higher in boys at both a relative (63% higher) and absolute (37% higher) running speed compared to men[1]. SF/SL decreases with age and therefore it is difficult to determine if the decrease is related to improved running economy or growth. Rowland et al. found no relationship between SF/SL and running economy between boys and men[2]. The participants within each group in that study were similar in running ability, and all reported being physically active. The authors concluded that the similarity in running ability might explain why no relationship between SF/SL and running economy was found.

While it is thought that running mechanics, specifically stride frequency, stride length, and leg length, play a role in children have inferior walking and running economy, one study found contrasting results. Allor et al. found that when adolescent girls and adult women were matched for height and weight, there was no difference in leg length and stride frequency between groups. The girls were still less economical during submaximal walking and running[4] indicating that body size explains some of the difference in economy between children and adults but not all. Very limited information is available on leg length as a predictor of economy. Future research should focus on leg length, not only stride frequency and stride length, as a factor related to economy.

Substrate utilization

Substrate utilization is different between children and adults[10, 39, 40]. Substrate utilization is commonly estimated by the respiratory exchange ratio (RER) during steady-state, submaximal exercise. A lower RER (VCO_2/VO_2) suggests that more fat is utilized compared to carbohydrate at a given intensity. When comparing children and adults, children have a lower RER during the same absolute[2, 41] and relative[10, 39, 42] exercise intensity. Montoye et al. found that RER increased with age in boys when walking on a treadmill at 3 mph and 3% grade[41].

Foricher et al. found that boys compared to men had a lower RER when cycling at 40% and 60% VO_{2max}[39]. Children, therefore, appear to be less carbohydrate-dependent during exercise when compared to adults.

Differences in substrate utilization can also be seen between children and adolescents. Timmons et al. found that when boys 12 and 14 years old cycled at 70% VO2peak, the boys who were 12 years old had significantly higher fat utilization than the 14 year old boys[43]. There was also a difference in total carbohydrate utilization (CHO_{total} mg/kg/min) between the two groups with the 12 year olds using less carbohydrate, but this did not reach statistical significance. When comparing RER, the 14-year-old boys had a significantly higher value compared to the 12 year olds. Similar results were found comparing girls 12 and 14 years old. The younger girls had significantly higher fat oxidation and lower endogenous carbohydrate oxidation during exercise[44]. Higher fat utilization during exercise would result in greater oxygen consumption, as more oxygen is needed to metabolize fat compared to carbohydrate[45].

The difference in substrate utilization between children and adults, with children using more fat, has been thought to be a factor related to poorer economy in children[10]. Martinez and Haymes found that when girls (9.1±0.6 years old) and women (24.4±5.2 years old) exercised at the same relative intensity (~70% VO2max), RER was found to be significantly lower for the girls[10]. At an absolute intensity (7.2km/h), there was no difference in RER between girls and women except at minute five when the girls had a higher value[10]. Maliszewski and Freedson found similar results[1]. They found that boys had a significantly lower RER compared to men (0.93±0.029 vs 0.98±0.055) when running at a relative intensity of 3.71 leg lengths per second[1]. Results from both of these studies support the idea that children utilize more fat than adults during exercise. It is unknown to what affect this difference in metabolism has on economy.

Energy expenditure measured via indirect calorimetry provides information for the amount of energy derived during exercise (approximately 5kcal/L). While aerobic metabolism contributes the majority of energy used during steady state submaximal exercise, a small but significant proportion comes from anaerobic metabolism[46]. Children rely less on their glycolytic capacity or anaerobic capacity compared to adults during exercise[1]. An under-utilized glycolytic capacity has been supported by children having lower lactate levels[10], lower muscle phosphofructokinase and other limiting enzymes involved in glycolysis, and lower muscle power. It is unknown whether a diminished anaerobic capacity plays a role in children having impaired economy compared to adults. Future research should focus on change in substrate utilization during exercise at defined submaximal workloads including below and above the ventilatory threshold between children and adults as a factor related to economy.

Ventilation

The onset of exercise is accompanied by an increase in minute ventilation (L/min). This increase in ventilation is caused by an increase in both tidal volume (ml) and breathing frequency (bpm)[27]. With exercise up to ~60% VO_{2max}, there is a linear increase seen between VO_2 and ventilation[27]. This increase in ventilation is due primarily to an increase in tidal volume[47]. Above ~60% VO_{2max}, excess CO_2 is produced due to the buffering of lactate by bicarbonate and this excess needs to be removed via ventilation[27]. The continued increase in ventilation above ~60% VO_{2max} is due to primarily increase in breathing frequency[47]. The increase in ventilation comes with a metabolic cost. In a healthy adult participating in maximal exercise, ventilation accounts for approximately 10-14% of total energy cost[27]. Differences in ventilation between children and adults may result in a difference in energy expenditure and explain some of the variation in submaximal VO_2.

During exercise, children have a higher breathing frequency and lower tidal volume compared to adults. Rowland et al. found that boys had a significantly higher ventilation during submaximal treadmill running compared to men (0.137±0.025 vs. 0.098±0.014 L/min/kg)[2]. Boys also had a significantly higher breathing frequency compared to men (60±13 vs. 33±8 breaths/min). Similar results were found for females, with girls having a higher submaximal ventilation (1.01±0.09 vs. 0.82±0.17 L/min) and a higher breathing frequency (50±10 vs. 32±5 breaths/min)[3]. They further found that girls had a lower tidal volume compared to women (2.08±0.36 vs. 2.63±0.56 ml/kg x 10^2). However, children and adults in both studies were not matched for body size.

The differences seen in ventilation may be partially explained by body size. Total lung capacity is most correlated with height and increases by approximately 3,100 cm^3 from age 5 to 14[27]. However, Allor et al. found that adolescent girls had significantly greater ventilation (~18 percent) and breathing frequency (6 breaths per minute during walking, 9 breaths per minute during running) compared to women matched for height and weight during submaximal walking and running[4]. This suggests that other factors such as age or maturation in addition to body size may explain differences in ventilation.

Rowland et al. found that boys have a greater ventilatory equivalent for oxygen (VE/VO_2) compared to men[2]. This means that at a given workload (VO_2), children have either a higher breathing frequency or greater depth of tidal volume compared to adults. Maliszewski and Freedson found that at both an absolute (9.6kph) and relative (3.71 leg lengths per second) intensity, men had higher ventilation (L/min) than boys. This is to be expected due to the men being larger than the boys. However, boys had a higher VE/VO_2 than the men during an absolute (30.1±1.76 vs. 26.7±2.95) but not relative (28.9±1.74 vs. 28.1±3.86) intensity. Maximal ventilation (V_{Emax}) is ~30-40% lower than maximal voluntary ventilation (MVV) indicating that lung function does not limit exercise in healthy individuals[27]. Even given the differences between children and adults, it is unlikely that ventilation explains all of the differences in submaximal economy.

Percent body fat

Limited information is available on percent body fat as a factor related to economy. Browning et al. found when VO_2 was expressed as L/min, obese (thus having a increased percent body fat) men and women had a higher gross energy cost at six different speeds compared to normal-weight men and women[48]. However, when VO_2 was expressed relative to body mass (ml/kg/min), there was no difference in energy expenditure between obese and normal-weight participants[48]. Browning et al. found similar results in a different study[49]. Net metabolic rate or economy was similar between obese and normal-weight adults[49]. Ayub et al. compared walking economy in boys 11-18 years old matched for body mass. In each pair, one boy was obese (>30 percent body fat) and one was lean (<17 percent body fat)[20]. The authors found no significant difference in walking energy expenditure between the two groups at three speeds[20]. Results from this study suggest that body mass, not percent body fat, is related to economy. Due to the limited research available on percent body fat and economy, future research should focus on a measure of body composition as a factor related to economy.

Other factors

Training

Training has been suggested as one of the factors thought to influence running economy in children. Limited information is available in this area and results are mixed with some studies suggesting training influences economy[13, 50] while others have found no effect[51]. The majority of research in this area has been cross-sectional, and even when addressed longitudinally; it is difficult to distinguish between changes in running economy due to growth, training, or in combination.

In a cross-sectional study, Mayers and Gutin compared physiological characteristics of boys who were elite runners (~10.2 years old) compared to non-runners (~10.3 years old)[50]. They found that at three different submaximal speeds, the runners had a significantly lower submaximal VO_2 compared to the non-runners. The runners also had a lower RER and heart rate at each speed and were taller. The investigators also found that height was significantly correlated with VO_2 at 8mph in the runners (r=-0.80); however a correlation was not reported for the non-runners. When height was controlled for in the analysis, the difference in submaximal VO_2 between the runners and non-runners was no longer significant[50]. One limitation to this study is that the authors did not measure stride frequency or stride length. It is likely that running mechanics are highly correlated with VO_2 in the runners more so than height per se.

In a similar study, Krahenbuhl et al. examined factors thought to influence distance running performance in children[51]. Participants (boys 10 years old) were divided into two groups based on performance in a 1.6km run: at or above the 55th percentile or at or below the 45th percentile. Participants in the 46th to 54th percentile were excluded. Participants completed three submaximal runs at 134, 154, and 174 m/min and two all out 9-minute runs to measure performance. While there was a difference in performance in the 9-minute run with the fast group covering an average 1879m and the slower group running 1585m, there was no difference in submaximal running economy at all three submaximal speeds[51]. The participants in the fast group were found to have higher VO_{2max} and 4.5 minute post-exercise blood lactate levels compared to the slower running group[51]. These results suggest that blood lactate and VO_{2max} are more associated with distance running performance in children than running economy.

In a longitudinal study, Daniels et al. found that submaximal VO_2 decreases in boys from age 10-18 years [13]. Study participants were trained middle-distance runners. Therefore, the authors concluded that improvement in submaximal running economy, with no change in relative VO_{2max}, was due to both age and training[13].

Krahenbuhl and colleagues conducted a follow-up study to determine if the improvement in submaximal running economy would occur in boys who were not trained runners[24]. While titled a longitudinal study, measurements were only taken on the six participants at two time points: ages 9 and 16. At both time points, participants ran on a treadmill at three different speeds for 6 minutes each. Speed was determined by age, with the participants running at faster speeds at age 16, in attempt to produce the same relative workload at both time points. When VO_2 was expressed by kilometers traveled, mean aerobic demand decreased by 13% from age 9 to 16 (234.2 vs. 202.8ml/kg/km). Similar to the study by Daniels et al.[52], change in submaximal running economy occurred without a change in relative VO_{2max}. The study by Krahenbuhl et al. concluded that run training is not needed for an improvement in running economy with increasing age[24]. It is worth pointing out that the improvement in running economy in the Krahenbuhl[24] study was not as great as that seen by Daniels[13], suggesting that run training may enhance the improvement in running economy that occurs with age.

In the studies discussed previously, participants were grouped by the amount of running they participated in or performance in a running race. Petray and Krahenbuhl examined the effect of instruction of running form and run training on running economy in a boys 10 years old. Participants were divided into five mutually exclusive groups ranging from no treatment as the control to receiving both run instruction and training lasting 12-weeks. Submaximal running economy was determined pre- and post-treatment by having participants run over-ground at 161m/min. No difference was found between the groups following the 12-week treatment, indicating that run training and instruction did not improve children's running economy.

It appears that training may have an influence on running economy, but the extent of this is still unknown. Daniels et al. found submaximal VO_2 decreases over a 22-month period in a group of boys who regularly participated in run training[53]. Daniels suggested that the change in submaximal VO_2 is the result of growth and an increase in anaerobic metabolism not training since participants in this study were already involved in run training prior to testing[53]. Future studies should attempt to control for training level of participants as that may influence their current economy and change over time.

Running biomechanics

Children and adults differ in their running biomechanics due to a number of factors. Children have a greater vertical movement with each stride, increased hip, knee, and ankle extension at takeoff, increased time in the nonsupport phase of the stride, and a decrease in the relative distance of the support foot ahead of the body's center of gravity at contact[2]. Each of these differences in running mechanics between children and adults could contribute to the inferior economy seen in children.

Williams and Cavanagh (1987) found that adult running economy is influenced by a number of biomechanical variables[54]. In a regression analysis, they found mechanical power, maximal plantar flexion angle, and shank angle at foot strike explained 54% of the variance in running economy. They conclude, however, that differences in running economy among individuals cannot be attributed to one or two biomechanical factors and are instead influenced by many variables[54]. With such variability in biomechanical factors in adults, one would expect a difference among youth of different ages.

Hausdorff et al. found stride-to-stride variability during walking to be significantly different among children of varying ages[55]. They found the greatest variability in children (boys and girls) at age four, less variability at age seven, and the lowest variability at age eleven. The stride-to-stride fluctuations of the eleven and seven year olds were similar to those seen in adults. The authors further found a difference in gait dynamics among children of different ages[55]. Stride dynamics of children seven years old were not be fully developed while those of 11 to 14 year olds had similar values compared to adults. It was previously thought that children age three had a mature walking gait[56], however results from this study suggest children even at age seven had not reached a fully mature gait[55]. Norlin et al. found similar results that temporal phases, velocity, and stride length all change with age and this does not happen in a continuous manner[57]. They found that development of a child's gait continues until age 16, and the most drastic changes occur at approximately age eight to ten[57]. Variability in biomechanical factors among individuals is difficult to study thus making it difficult to include these variables as in studies related to walking and running economy.

Frost et al. further found that there is a difference in cocontration between children and adults[12]. Cocontraction is when agonist and antagonist muscles, for example the quadriceps and hamstrings, simultaneously contract. Cocontration occurs minimally during running and walking. However, if contraction of both muscles is not needed this can cause an increase in energy expenditure. Frost et al. found concontraction to be higher in younger children and decrease with age during walking and running, although these differences were not always statistically significant[12]. The authors measured VO_2 and found younger children to have a significantly higher VO_2 during walking and running. Results from this study indicate that the higher energy expenditure in young children during walking and running may be partially explained by cocontration[12]. Biomechanical factors related to running are often not included in studies related to economy. Future research should include the biomechanical factors discussed previously as they may explain some the difference in economy between children and adults.

Treadmill versus overground

The majority of previous research examining economy has required participants to walk or run on a treadmill. The use of a treadmill allows for standardization of speed among subjects. However, energy expenditure during walking or running at a given speed may vary between treadmill and overground. Pearce et al. found when adults walked on a treadmill and overground there was a significant difference in energy expenditure[58]. At 3.0mph, participants expend more energy walking overground (11.04 ml/kg/min) compared to on a treadmill (10.58

ml/kg/min). The difference in energy expenditure is thought to be due to the lack of air resistance on the treadmill[59]. Jones et al. found that the grade of the treadmill should be set to 1% to account for the lack of air resistance[59]. Similar results were found by Davies[60], who found a 1% slope on a treadmill was equivalent to running outdoors overground. Future research related to economy should focus on overground walking and running since information from these studies could be use to predict energy expenditure in different populations.

Normalizing VO_2 to body size and allometric scaling

Often, children or adolescents of a given chronological age who are participating in a study are not the same body size; therefore reporting VO_2 in absolute terms (L/min) would be inappropriate. To account for these differences in body size among participants, VO_2 is almost always normalized to body size to make comparisons meaningful[17]. Relative VO_2 is most commonly reported scaled to body mass (ml/kg/min). VO_2 is reported this way for a few reasons: 1) body mass is a relatively easy measurement, 2) the entire body mass is moved during running or walking, and 3) comparison can be made among studies[14]. However, reporting VO_2 scaled to body mass assumes there is a linear relationship between the two variables[14]. A number of studies have reported this to not be the case and have found a non-linear relationship between VO_2 and body mass[14]. Instead, allometric scaling or reporting VO_2 scaled to fat-free mass has been used.

When using allometric scaling, VO_2 is normalized to body size by an exponent representing body mass[61]. Allometric scaling, when all else is equal, is a way to show how a certain variable is related to body size[61]. The two most common exponents reported in the literature are 0.67 and 0.75[61]. While these two exponents could be used on an independent sample, the most appropriate method would be to calculate a body mass exponent specific to the sample being tested[14]. Statistical analysis required in allometric scaling can be difficult, making this approach unfavorable compared to simply dividing by body mass. The use of sample-specific exponents makes comparison across studies difficult if not impossible.

As reported in this review, when VO_2 is reported as a ratio with body mass, children are less economical than adults during walking and running[2, 3]. It is important to note that when allometric scaling is used to report VO_2, adult-child differences tend to become non-significant. Welsman and Armstrong conducted a longitudinal study on changes in submaximal VO_2 in both girls and boys age 11-13 years using allometric scaling to report VO_2[33]. The sample-specific body mass exponent was 0.88±0.02. They found VO_2 was not significantly different from age 11 to 13 years, thus indicating that the simplified VO_2 to body mass ratio may not be the most appropriate. While the exponent 0.88 is similar to other values found in children (0.65-0.93)[33], it only applies to this specific sample. Allometric scaling may show promise as a more appropriate way to report VO_2; however, the results are not generalizable across studies.

Another approach has been to normalize VO_2 to fat-free mass instead of body mass. The rationale is that only fat-free mass is participating in oxygen consumption[14]. Janz et al. found fat-free mass to be the most appropriate method for normalizing VO_2 in boys and girls[62]. However, there are different methods to estimate fat-free mass including dual x-ray absorptiometry (DEXA), underwater weighing, air displacement plethysmography (BodPod), bioelectrical impedance analysis, and skinfolds. These various measurement techniques may be difficult and/or expensive, and have errors ranging from 2-4% whereas body mass is a relatively simple measurement with much less measurement error. It also may be inappropriate to exclude fat-mass because total body mass is what is being moved during walking and running[14].

A third method proposed is to normalize VO_2 to body surface area. In a longitudinal study of males 13-27 years old, Spencer et al. found body surface area to be the most appropriate method for normalizing VO_2[14]. In this study, VO_2 was also reported as the traditional VO_2 to body mass ratio, VO_2 to fat-free mass, and by allometric scaling. To the author's knowledge, no other study has compared all four methods for reporting VO_2. Two cross-sectional studies by Rowland found adult-child differences in VO_2 when expressed relative to body mass[2, 3]. However, when VO_2 was expressed relative to body surface area, the difference in submaximal VO_2 was no longer significant. While VO_2 to body surface area may be a more appropriate way to normalize VO_2, few studies have used this method making comparison and generalizability difficult.

Non-locomotor studies on economy

The majority of research conducted on economy in children and adolescents has focused on walking and running. One study by Rowland et al. examined differences in mechanical efficiency during cycling between boys and men[63]. In this study, no difference was found in mechanical efficiency when the two groups rode at both an absolute (watts) and relative intensity (percent VO_{2max}). To the author's knowledge, no information is available on changes in economy in children participating in other lifestyle activities. For example, it is unknown whether economy improves in lifestyle activities that require more lateral movement such as dance aerobics, sweeping, and shooting hoops that would be similar to the change in economy observed in walking and running. If economy improves in these lifestyle activities, it is also unknown whether the same factors that affect economy in walking and running might influence economy in these activities.

Summary

When VO_2 is expressed relative to body mass (VO_2 ml/kg/min), children are less economical than adults and adolescents. A number of factors previously discussed are thought to contribute to adult-child differences in economy. Maturation is thought contribute to changes in economy but due to the difficulty of measurement, it is rarely included. The majority of previous research is cross-sectional, which may not fully capture changes in economy. Limited information is available on longitudinal changes in economy in children and adolescents and the information that exists is confined to the context of walking and running. It is unknown whether changes in economy occur in other lifestyle activities. Further research is needed to determine longitudinal changes and factors related to these changes in economy during walking, running, and other lifestyle activities.

CHAPTER 3

FACTORS THAT INFLUENCE WALKING AND RUNNING ECONOMY IN CHILDREN AND ADOLESCENTS: A MIXED LONGITUDINAL APPROACH

Abstract

Several factors are postulated to contribute to the improvement in children's walking and running economy with age. Most studies examining these factors have been limited by cross-sectional design. Longitudinal studies are needed to better examine factors influencing economy. **PURPOSE:** To identify factors that influence change in walking and running economy expressed as absolute (VO_2, L/min) and relative (VO_2, ml/kg/min) oxygen consumption over four years in children and adolescents. **METHODS:** Participants age 6-16 years (N=223; 116=males, 107=females) participated in a mixed longitudinal study. During year one, participants completed an overground walking and running trial, each lasting five minutes, at a self-selected pace around a course of known distance. The same self-selected pace was used for the subsequent years of the study. Expired gases were collected using indirect calorimetry via a portable metabolic analyzer to estimate VO_2. Hierarchical linear modeling was used to create two separate models (L/min and ml/kg/min) for walking and running. Potential influential factors, assessed annually, were identified including body surface area (BSA), leg length (LL), resting energy expenditure (REE), ventilation (VE), percent body fat, maturity status, and stride frequency (SF). Covariates were chronological age (CA), gender, and weight (for L/min models only). Significant factors were determined independently using 2 x standard deviation (SD) approach and then included in a model of best fit. **RESULTS:** With respect to the absolute models (L/min), VO_2 increased by 0.02

L/min for walking and 0.13 L/min for running per year. Model fit, identified by deviance, did not improve with the addition of time or covariates to the model for walking. For running, the covariate gender was significant with females more economical ($p<0.05$) but no significant predictor variables were identified. With respect to the relative models, VO_2 (ml/kg/min) decreased by 1.19 for walking and 0.87 ml/kg/min for running per year. Significant individual variation for VO_2 over time was found for walking ($p<0.001$) and running ($p=0.02$). For walking, BSA, VE, and CA were significant at the slope level in the final model ($p<0.05$). Variance in slope remained significant in the final model meaning change in economy over time was not fully explained by the factors included in the model ($p=0.010$). For running, LL was significant at the slope level in the final model. Slope variance remained significant for running as well ($p=0.049$). **CONCLUSIONS:** Expressing VO_2 in absolute terms (L/min) may not be an appropriate method to identify factors related to economy. In comparison with previous literature, when VO_2 was expressed in ml/kg/min, only BSA, VE, and CA were identified as significant influential variables of walking economy. In contrast to previous literature, LL not SF, was identified as a significant influential variable of running economy. Since individual variation for slope in the final model was significant for both walking and running, others factors not included here may further explain change over time in economy in children and adolescents.

Introduction

Economy is defined as the aerobic demand or energy cost required to perform a submaximal exercise task[1]. When performing a given submaximal activity, lower energy expenditure, commonly reported as VO_2 relative to body mass (ml/kg/min), is considered more economical. Studying the change in economy from childhood through adolescence is important as it addresses differences in energy expenditure during various activities and thus influences the ability to accurately predict energy expenditure in this population. This is important as it relates to the compendium of physical activities for children and adolescents as well as performance in different sports (i.e. running performance). Previous cross-sectional studies have found children to be less economical than adults[1-4, 6]. While cross-sectional studies provide insight into differences between groups, they are limited to one time-point and do not assess change within individuals. Longitudinal studies are valuable as they involve following the same participants over time, which provides a better understanding of the development of the variable being studied.

Previous longitudinal studies have been limited to children or adolescents or males or females walking or running on a treadmill[5, 13, 22-24, 33, 64]. Daniels et al. found VO_2 decreased from age 10-18 years old in boys who were trained middle-distance runners with no change in relative VO_{2max}[13]. The authors concluded that the decrease in VO_2 was due to both age and training. Ariens et al., using data from The Amsterdam Growth and Health Study (AGHS), found running economy improved in both males and females from age 13-27 years old[5]. The greatest improvement in running economy was seen during adolescence. From 13-16 yrs, VO_2 decreased by 5 ml/kg/min followed by only a 2 ml/kg/min difference from age 16-27[5]. In children, Morgan et al. found energy expenditure (VO_2 ml/kg/min) to be 27% higher in 6 year olds compared to 10 year olds across six different speeds on a treadmill[23]. Previous literature has focused primarily on change in economy in either children or adolescents over time. We found no study that has examined change in economy in both walking and running overground over time in children and adolescents.

A number of factors are thought to contribute to inferior walking and running economy in children compared to adults, including age[2, 3], resting metabolic rate (RMR)[7, 8], body size[1], gender[9], substrate utilization[10], biomechanics[11, 12], training[13], ventilation[2], and maturation[14]. There are data, although in some cases limited, to support each factor and its influence on differences in walking and running economy between children and adults. However, no study has been able to explain definitively why this difference in economy occurs.

The primary purpose of this study was to examine longitudinal changes in walking and running economy expressed as absolute VO_2 (L/min) and relative VO_2 (ml/kg/min) over four years in children and adolescents. The secondary purpose was to determine predictor variables that influence this change in economy over the four years. It was hypothesized that walking and running economy would improve over the four years for both absolute VO_2 and relative VO_2. It was further hypothesized that chronological age and BSA would explain the greatest amount of variance in walking and running economy. Stride frequency was also hypothesized to significantly contribute to economy, but maturation, gender, REE, leg length, percent body fat, and ventilation were not hypothesized to be significant predictors of walking and running economy.

Methods

Participants

Two hundred and thirteen participants were recruited to take part in a mixed longitudinal study. Participants were a convenience sample, recruited from two different sites, Michigan State University (n=108) and Oregon State University (n=105), through email, local recreational facilities, and word of mouth. Participants were between 6 and 15 years old for the first visit of year 1 with the goal of having at least 5 girls and five boys for each age per site. Table 1 shows the number of subjects by year categorized by chronological age and gender.

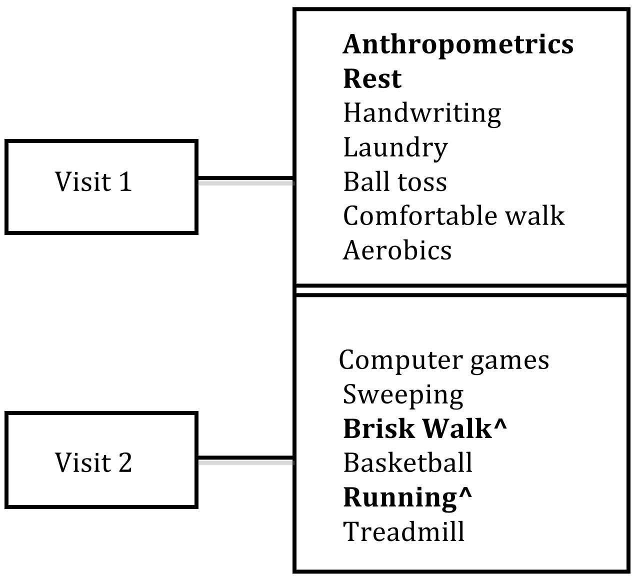
Table 1: Number of subjects by chronological age, gender, and test year.

	Test Years				
Age group (yrs)	Year 1	Year 2	Year 3	Year 4	Total
6	2(4)				2(4)
7	8(4)	2(4)			10(8)
8	7(8)	8(4)	2(4)		17(16)
9	10(7)	7(7)	8(4)	2(4)	27(22)
10	11(14)	10(8)	7(7)	8(4)	36(33)
11	10(8)	11(14)	10(8)	7(7)	38(37)
12	10(6)	10(8)	11(14)	10(8)	41(36)
13	8(14)	10(6)	10(8)	11(14)	39(41)
14	10(7)	8(14)	10(6)	10(8)	38(35)
15	1(3)	10(7)	8(14)	10(6)	29(30)
16	0(1)	1(3)	10(7)	8(14)	19(25)
17		0(1)	1(3)	10(7)	11(11)
18			0(1)	1(3)	1(4)
19				0(1)	0(1)
Total	77(76)	77(76)	77(76)	77(76)	

n=153; Boys (girls)

Each participant attended two individual visits annually over four years at one of the two sites. Participants were subsequently scheduled to return to the laboratory for data collection within a 3-month window of the previous year. For the purposes of this study, only data collected from V1 and V2 were used for each of the four years. Figure 1 shows which activities were completed each year during V1 and V2.

Figure 1. Flow chart for visits 1 and 2. Repeated for years 1-4.



Bold activities used in this study. ^Step count collected from minutes 2:30-3:00 and 3:30-4:00.

During the initial visit for year one, parents completed a medical history Physical Activity Readiness Questionnaire (PAR-Q), to determine if their child was able to participate. Physical activity requirements for this study were no greater than what children experience during recess or physical education class. Due to this study being part of a larger accelerometry validation study for which participants wore accelerometers during data collection, children were excluded if they had orthopedic abnormalities or were in a wheelchair. They were also excluded if they had a medical condition that increased the risk associated with participating in physical activities. Each parent completed a PAR-Q prior to each year of testing to ensure no new medical conditions had occurred over the last year. The two visits each year were separated by at least 24 hours and no more than three weeks. Participants were instructed to not participate in vigorous physical activity the day of testing and to not eat for two hours prior to testing. The institutional review boards at Michigan State University and Oregon State University approved this study. Parental consent and participant assent were received prior to testing at the first visit of each year.

Measures

The different measures assessed during this study include anthropometrics, energy expenditure, and factors related to economy. Anthropometric measures taken in this study were body mass (kg), stature (cm), seated height (cm), and waist circumference (cm). Body fatness was also assessed via skinfolds. Duplicate measures of body mass, stature, and seated height were taken. Waist circumference and skinfold measures were taken in triplicate. Stature and seated height were measured using a wall-mounted stadiometer (Seca 222) to the nearest 0.1cm. For each measurement, the participant's head was positioned in the Frankfurt horizontal plane. If the two measurements were not within 1.0 cm, a third measurement was taken. The two measurements within 1.0 cm were then averaged. Body mass was measured to the nearest 0.1 kg using a Seca portable electronic scale (Seca 770). If the two measurements were not within 0.5 kg, a third measurement was taken. The two measurements within 0.5 kg were then averaged. Measurements of body mass, stature, and seated height were taken without the participant wearing shoes[65]. Waist circumference was measured in accordance with NHANES III protocol[66]. Participants stood with their weight evenly distributed. The research assistant palpated the participant's right hip to find his/her right iliac crest. A horizontal mark with a vertical cross at the midaxillary line was made with a washable marker slightly above the lateral border of the iliac crest. An identical mark was made just above the lateral border of the left iliac crest. A Gulick tape measure was then placed around the participant in line with the two marks and parallel to the ground. A measurement was recorded to the nearest 0.1 cm when the participant was at minimal normal respiration. If the three measures were not within 1.0 cm, a fourth measurement was taken. The three measurements within 1.0 cm were then averaged. Using Lange calipers that had been properly calibrated, skinfold measurements were taken at the triceps and medial calf to the nearest millimeter on the right side of the body. Triplicate measures from each skinfold site were taken and an average was computed. If a measure was not within 2 mm, a fourth measure at that site was taken, and the three measurements within 2 mm where averaged.

Energy expenditure was estimated during each submaximal activity by the Oxycon Mobile portable metabolic analyzer (Care Fusion, San Diego, CA). The Oxycon Mobile was calibrated for ambient conditions, volume flow, and gases prior to each subject being tested. Each participant was fitted with a vest, mask, and headgear prior to each visit. A mask was fitted to each participant's face so that there was a seal around the nose and mouth, allowing no air to leak. Headgear was then fitted based on the participant's head size and attached to the mask. A Triple-V from the Oxycon Mobile was then attached to the mask. During a 10-minute pre-exercise rest trial, only the mask and headgear were worn due to the participant lying supine on a mat. Each participant was then fitted with a vest. The vest was fitted so that it was tight enough not to move around during the activity trials while not restricting a participant's movement or breathing. The SBx and DEx from the Oxycon Mobile were strapped to the vest on the back of the participant. During each 5-minute trial, metabolic measures included VO_2, VCO_2, VE, and RER (VCO_2/VO_2) and were assessed breath-by-breath by the Oxycon Mobile. The breath-by-breath measurements were then aggregated by 10-seconds. Data reduction consisted of averaging these 10-second values over a two minute time period for each activity. Minutes 2:30-4:30 were used for data analysis for each activity. Heart rate was measured by telemetry and aggregated by 10-seconds. Heart rate values were then averaged over a two-minute period (2:30-4:30). In the instance that telemetry with the Oxycon was lost, a Polar heart rate watch was then used.

Factors assessed in this study related to economy included: chronological age, gender, maturation, resting energy expenditure, body surface area (BSA), stride frequency, ventilation, leg length, and percent body fat. Chronological age was determined by subtracting each participant's birth date from the test date. Gender was self-reported prior to the first visit of year one. Maturation was obtained by calculating predicted age at peak height velocity (APHV) using the equation developed by Mirwald et al.[67]. APHV was calculated for each participant at all four-time points. Due to the age of some participants, only one calculation was found to be valid (within ±4 years of maturity age), therefore that APHV was used. For participants with more than one valid maturity age, the predicted value that was closest to their APHV (closest to a maturity offset of 0) was used. For example, if a participant had two valid APHV calculated over the four time points, the maturity age where the participant was closest to his/her APHV was used (personal communication, Dr. Adam Baxter-Jones). After APHV was determined, each participant was coded as pre-APHV (0) or post-APHV (1) for analysis. Resting energy expenditure (REE) was determined from the 10-minute pre-exercise rest trial. Participants were supine on a mat for 10-minutes while metabolic measures and heart rate were collected via the oxycon mobile. VO_2 collected during minute's 7:30-9:30 was then averaged to determine REE. Body surface area was calculated for each participant at each visit using the Haycock equation[68]: BSA (m^2) = 0.024265 x Height(cm)$^{0.3964}$ x Weight(kg)$^{0.5378}$. Stride frequency was determined by collecting two 30-second step counts during each walking and running trial and averaging results from the two counts. Leg length was calculated each year by determining a participant's trunk length (standing height-(seated height-height of the stool (73.65 cm), then subtracting this value from standing height . Percent body fat was determined from calf and triceps skinfolds using the gender specific Slaughter equations for children and adolescents[69].

Procedures

Participants came to the Human Energy Research Laboratory (HERL) at Michigan State University or the Physical Activity Assessment Laboratory (PAAL) at Oregon State University for two visits annually (V1 and V2) over a four-year period.

Annual visits for each participant were completed within a +/- 3-month window of when they came to the laboratory the previous year. This resulted in a total of eight visits to the laboratory.

Participants came to the laboratory following a 2-hour fast and refraining from any vigorous physical activity on the day of testing. Visit 1 consisted of six activities: rest, handwriting, laundry, ball toss, comfortable walk, and dance aerobics. Visit 2 consisted of six different activities: computer games, sweeping, brisk walking, basketball (shooting hoops), running, and treadmill walking. For this study, only overground brisk walking and running were used in analysis, both of which were performed in V2. Figure 1 is a flow chart of all activities.

Upon arrival to the laboratory for V1, anthropometric measures were taken and each participant completed the 10-minute rest trial. Participants wore the Oxycon Mobile portable metabolic analyzer (San Diego, CA) to assess metabolic measures (VO_2, VCO_2, VE, RER) throughout each activity. After anthropometric measurements were taken, participants were fitted with a mask and vest for the Oxycon Mobile. The mask was fitted so that no air was leaking, ensuring that all expired air was being analyzed and that the appropriate dead space was set in the Oxycon Mobile program. Participants also wore a heart rate monitor, which sent information via telemetry to the Oxycon Mobile.

During V2, each participant completed an over-ground brisk walk (BW) trial at a self-selected pace over a course of known distance (632" x 604") in a large gymnasium. Participants were instructed to walk at a brisk pace around the marked course. Research assistants read a standardized script that explained the trial.

> "For the next 5 minutes, I want you to walk around the marked area at a fast pace. However, I do not want you to run. The only difference between this test and the previous walking test is that I would like you to walk at a faster pace than before. One person will walk with you the whole time to help you keep the pace. Also, during the trial I will be communicating back and forth with [name of person running Oxycon] so do not pay attention to that, just focus on walking at a consistent speed."

Participants selected their pace during the first lap, and research assistants helped them maintain the pace throughout the duration of the trial. The trial lasted exactly five minutes. Expired gases and heart rate were recorded throughout the entire five minutes. During the trial, times for laps two through four were recorded in seconds. Stride frequency was determined using a counting clicker from minute 2:30-3:00 and 3:30-4:00.

The same measurements were taken during the running trial as the BW trial. A standardized script was read to each participant prior to the start of the running trial.

> "For the next 5 minutes, I want you to jog around the marked area without stopping, if possible; therefore, try and pace yourself in the beginning. Because 5 minutes is a long time, one person will jog with you the whole time to help you keep an even steady pace. During the first minute or two we will figure out how fast you are going, and during the rest of the trial, we want you keep that same pace. Also, during the trial I will be communicating back and forth with [name of person running Oxycon] so do not pay attention to that, just focus on running at a consistent speed."

Participants returned to the laboratory annually for three years (36 month period). Each year, each participant completed visits 1 and 2. The brisk walk and running trials were all repeated with the same procedures and measurements taken as in year 1. Walking and running pace of each trial in subsequent years were not self-selected but instead matched for year 1. For example, for the brisk walk trial, participants walked at the same pace determined during year 1 for years 2-4. A research assistant who set the walking pace based on the pre-determined lap splits from year 1 accompanied each participant. Prior to each trial, a standardized script was read to each participant.

> "For the next 5 minutes, I want you to walk around the marked course at the same speed as last year's comfortable walk trial. I will walk with you the whole time to set the pace. It is important that you keep pace with me throughout the whole trial. During each lap, you will hear a beeping noise from my watch. This helps me keep the right pace. Also, during the trial I will be communicating back and forth with my co-worker so do not pay attention to that, just focus on walking at a consistent speed."

Data Reduction

Throughout V1 and V2, the Oxycon Mobile portable metabolic analyzer collected continuous metabolic data breath-by-breath. The data were then aggregated to 10-seconds. Every activity was five minutes in duration. Minutes 2:30-4:30 were selected for each activity for every participant in the data reduction software specifically designed for this study. The 10-second values from 2:30-4:30 were averaged for all metabolic measures (VO_2 (ml/kg/min), VO_2 (ml/min), VCO_2 (L/min), VE (L/min)) and saved in a database. For analysis, the dependent variable, VO_2, was expressed as L/min and ml/kg/min.

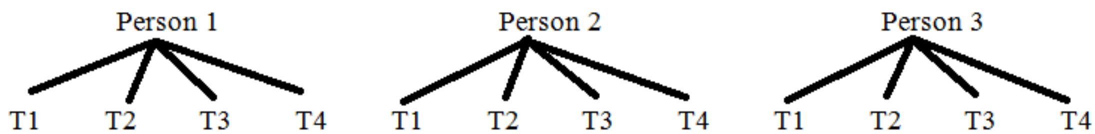
To determine outliers in the data, standard deviations and z-scores were calculated and examined for each variable for each participant. A variable for a participant was deleted if his/her z-score was less than -3 or greater than 3. Pearson correlations and variance inflation factors (VIF) from multiple linear regression were used to determine multicollinearity among predictor variables. Multicollinearity was identified if a predictor variables had a VIF greater than 10. In order to compare models in Hierarchical Linear Modeling (HLM) using deviance, models must be completely nested. This means that if a participant was missing one variable (i.e. VO_2 at one time point or APHV), all data for that participant were deleted.

Analysis

The analytical plan for this study involved descriptive statistics and hierarchical linear modeling (Aims 1 and 2) to determine longitudinal changes in economy and time varying and time invariant factors that influenced changes in economy in children and adolescents. It is accepted that a power analysis for HLM is generally not conducted[70]. The corresponding hypotheses from Aims 1 and 2 were tested together in one model (e.g., Aim 1 Hypothesis 1 was tested simultaneously with Aim 2 Hypothesis 1). The first hypothesis in each pairing examined longitudinal changes in economy and the second determined factors that influenced change in economy over time.

Growth curve analysis using HLM was used for Aims 1 and 2. For each analysis, the level 1 model was a repeated measure of time; the level 1 model identified how VO_2 changed over the four years. This represented the change we anticipated each participant to have over the four years in this study (within-person change over time). The level 2 model assessed individuals; the level 2 model identified independent (predictor) variables that influenced how the dependent variable (VO_2) changed over time. This represented relating identified predictors to inter-individual differences to change (between-person change over time). Figure 2 is a graphical example of level 1 (time) and level 2 (individual) models in a growth curve analysis.

Figure 2: Different levels in a growth curve analysis.



The following analyses were separately performed:

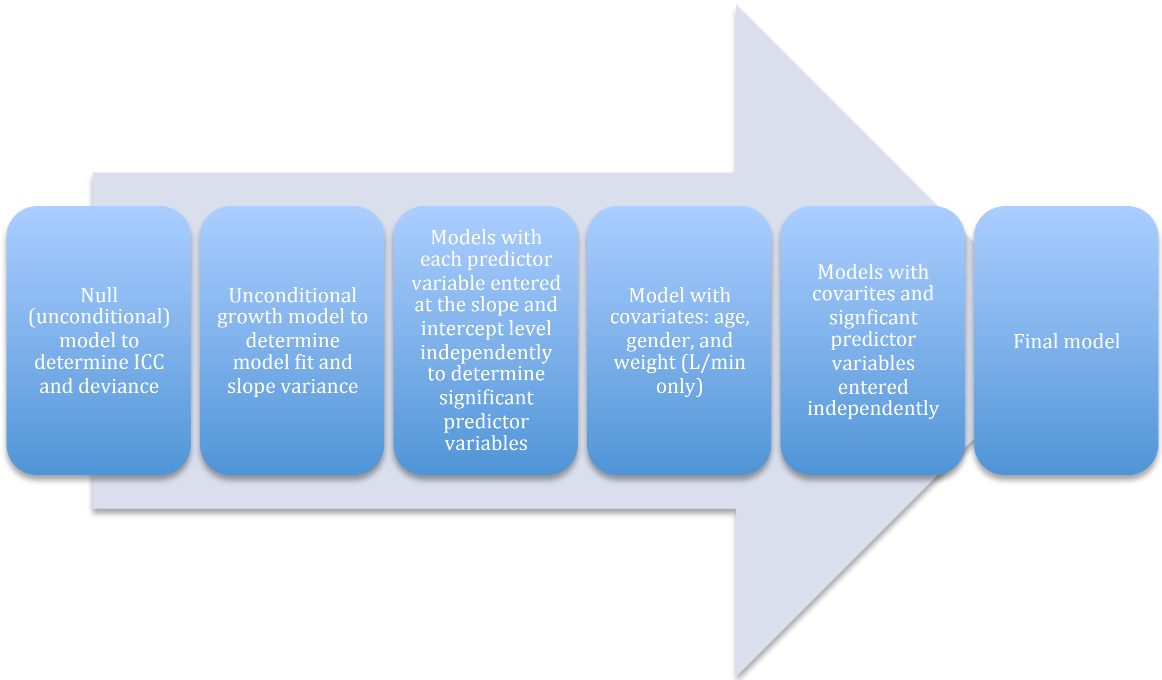
Analysis 1: Aim 1 Hypothesis 1 and Aim 2 Hypothesis 1 assessed longitudinal change and predictors of walking economy (expressed as both absolute and relative VO2).

Analysis 2: Aim 1 Hypothesis 2 and Aim 2 Hypothesis 2 assessed longitudinal change and predictors of running economy (expressed as both absolute and relative VO2).

Using HLM, a null (unconditional) model, which included only the dependent variable, VO_2, was run for both absolute and relative VO_2 ($Y_{ti} = \pi_{0i} + \pi_{1i} + e_{ti}$). The purpose of this model was to determine deviance (-2 log likelihood) and number of parameters for model comparison. Full maximum likelihood was selected. From the null model, the inter-class correlation was calculated. ICC varies from -1 to +1. When ICC is close to 0 or negative, there is large within group variance but little group mean difference and using HLM is not appropriate. HLM is appropriate when ICC is close to +1. There is then a large group mean difference but little within group variance. Using deviance and number of parameters from the null model, an unconditional growth model was run. The unconditional growth model included the dependent variable, VO_2, and time (uncentered) in level 1 ($Y_{ti} = \pi_{0i} + \pi_{1i}TIME_{ti} + e_{ti}$). Time was coded as 1 (year 1), 2 (year 2), 3 (year 3), and 4 (year 4). The error term associated with the slope was also included (r_{1i}). Comparison between the null model and the unconditional growth model allowed for determining if the unconditional growth model was a better fit than the null model and if there was variance between individuals in the slope of the line. If there was no variance in the slope, there was no difference between individuals, and predictor variables were not needed. If the model did not improve (deviance moved farther away from 0), the addition of time to the model did not improve the model fit, meaning there was no change in slope overtime (non-linear model). A null model and unconditional model were run for walking VO_2 (L/min and ml/kg/min) and running VO_2 (L/min and ml/kg/min). If model fit improved from the null model to the unconditional model, and variance of the slope was significant (did not equal 0), further analysis took place.

Using deviance and number of parameters from the unconditional growth model, predictor variables were entered one at a time in level 2 as fixed effects (β), both at the intercept (π_{0i}) and slope (π_{1i}), to determine the independent effect of each predictor variable. Predictor (independent) variables included BSA, SF, maturity, REE, LL, percent body fat, and VE. These predictor variables were also considered predictors of the intercept, meaning they may cause the starting point of the intercept to change, and were incorporated into the model at the intercept (π_{0i}) for this reason. Significant predictor variables were identified using 2 x SD at the slope level of level-2. For both walking and running absolute and relative VO_2, a model was then created that included all covariates using deviance and number of parameters from the unconditional growth model. Covariates for the walking and running absolute VO_2 models included chronological age (CA), weight (kg), and gender. Covariates for the walking and running relative VO_2 models included CA and gender. Gender and maturity were categorical variables while CA, weight, leg length, BSA, SF, REE and ventilation were continuous variables. Gender was a time invariant variable (i.e., did not change over time). CA, weight, leg length, maturity, BSA, SF, REE, and ventilation were time varying variables (i.e., they change over time). Each significant predictor variable found in the previous models was then entered one at a time into the model that included the covariates. Significant predictor variables were identified. To determine the model of best fit, all significant predictor variables identified in the model that included the covariates were entered into a final model at the intercept and slope at level 2. A final model was created for walking VO_2 (L/min), walking VO_2 (ml/kg/min), running VO_2 (L/min), and running VO_2 (ml/kg/min). Figure 3 is a flow chart of the HLM analytical plan for this study.

Figure 3: HLM analysis plan.



Results

Two hundred thirteen participants were recruited during year 1 and participated in this study. Twenty-seven participants did not complete all four years of data collection leaving 186 participants for data analysis. HLM requires participants' data to be completely nested. This means that a participant is not missing any data points across the four years of data collection. For example, if a participant is missing walking VO_2 data for year 2, the data are not nested and that participant is excluded from data analysis for walking. Participants were excluded from data analysis if 1) calculated z-scores for the outcome variables (walking and running VO_2) or predictor variables were greater than plus or minus three or 2) participants had any missing data for the walking or running activities. For walking absolute VO_2 (AVO_2) and relative VO_2 (RVO_2), 10 subjects were excluded due to outliers identified by z-scores and 28 were excluded for having missing data (not nested) leaving 148 participants. For running AVO_2 and RVO_2, 10 subjects were excluded due to outliers identified by z-scores and 35 for having missing data leaving 141 participants. Table 2 shows total number of participants that were removed from analyses for walking and running.

Table 2. Participants removed from analyses for walking and running.

Physical Activity	Participants that did not complete all 4 years	Participants with missing data	Outliers by z-score	Final participant number
Walking	27	28	10	148
Running	27	35	10	141

Average walking speed was 3.4±0.4 mph (min 2.4; max 4.8) and average running speed was 5.1±0.9 mph (min 3.1, max 10.0). Intraclass correlations (ICC) for walking speed for years 1-2, 2-3, and 3-4 were 0.994, 0.992, and 0.98, respectively. ICC for running speed for years 1-2, 2-3, and 3-4 were 0.978, 0.957, and 0.989, respectively. Descriptive statistics for participants are presented in Table 3 for the walking and running trials.

Table 3. Descriptive characteristics and predictor variables by years.

Mean±SD	Year 1	Year 2	Year 3	Year 4
CA (yrs)	10.6±2.4	11.7±2.4	12.6±2.4	13.6±2.5
BSA (m^2)	1.26±0.27	1.35±0.27	1.44±0.26	1.52±0.26
LL (cm)	69.8±8.7	74.5±9.0	75.7±9.1	77.9±8.8
REE (ml/kg/min)	6.1±1.6	5.4±1.4	5.2±1.3	5.0±1.2
Height (cm)	144.6±14.8	150.5±14.8	155.3±14.2	159.7±13.2
Weight (kg)	40.3±13.5	44.5±13.4	48.5±13.3	52.8±14.0
Body Fat (%)	21.8±7.0	24.2±8.5	22.8±7.4	23.5±7.4
BMI Percentile	64.9±28.9	64.0±28.5	63.9±28.0	62.9±29.0
Walk VE (L/min)	22.8±5.5	23.2±5.7	24.0±5.8	23.8±6.2
Run VE (L/min)	47.3±15.0	49.0±13.6	52.8±15.0	52.3±15.2
Walk SF*	33.1±2.6	31.9±2.4	31.3±2.2	30.6±2.2
Run SF^	43.6±3.5	43.0±3.0	42.0±3.2	41.7±2.9

n=153 *n=148; ^n=141; LL = leg length; SF = stride frequency

Pearson correlations and VIF (Table 3) from multiple linear regression were run to determine multicollinearity among predictor variables. Correlation coefficients are shown in Table 4. A VIF of 10 for a predictor variable indicates multicollinearity[71]. Using multiple linear regression, all predictor variables for year 1 were entered into the model with VO_2 as the dependent variable. None of the predictor variables had a VIF over 10. Therefore, there was no multicollinearity among predictor variables, and all variables were entered into the HLM models.

Table 4: Pearson correlations among predictor variables.

	CA	BSA	LL	REE	Weight	BF%	WalkVE	RunVE	WalkSF	RunSF
CA	-	0.80	0.73	0.74	0.73	0.32	0.47	0.41	-0.60	-0.57
BSA	0.78	-	0.76	0.98	0.99	0.62	0.47	0.65	-0.61	-0.57
LL	0.73	0.76	-	0.70	0.73	0.28	0.66	0.81	-0.44	-0.45
REE	0.74	0.98	0.70	-	0.98	0.60	0.68	0.81	-0.59	-0.55
Weight	0.73	0.99	0.73	0.98	-	0.78	0.66	0.81	-0.57	-0.53
BF%	0.32	0.62	0.28	0.60	0.78	-	0.47	0.41	-0.24	-0.28
WalkVE	0.47	0.47	0.66	0.68	0.66	0.47	-	0.72	-0.17	-0.44
RunVE	0.41	0.65	0.81	0.81	0.81	0.41	0.72	-	-0.35	-0.43
WalkSF	-0.60	-0.61	-0.44	-0.59	-0.57	-0.24	-0.17	-0.35	-	0.61
RunSF	-0.57	-0.57	-0.45	-0.55	-0.53	-0.28	-0.44	-0.43	0.61	-

All correlations were significant ($p<0.001$)

For both walking and running, HLM was used to create models of best fit to determine change in VO_2 over the four years and identify predictor variables that influence change in VO_2. Two models were created for both walking and running. The first model included the outcome variable expressed as absolute VO_2 (L/min) and the second model with the outcome variable expressed as relative VO_2 (ml/kg/min).

Walking: Absolute VO_2 (AVO_2; L/min)

The null model, or unconditional model, included only the dependent (outcome) variable, which in this case was Walking AVO_2 (L/min). The null model was used to determine deviance (-2*likelihood), which was used to compare models, and to determine the Intraclass Correlation Coefficient (ICC). ICC is used to determine if multilevel model analysis is appropriate for data analysis. Using the null model, ICC is calculated as the intercept variance component (r_0)/(intercept variance component (r_0) + total variance component (e)). For walking AVO_2, ICC was calculated as 0.046/(0.046+0.015) = 0.75 or 75%, indicating that HLM was needed.

Deviance for the walking AVO_2 null model was -416.17 with 3 parameters. Since the data were nested, this deviance value was used to compare model fit.

Using deviance from the null model, an unconditional growth model was run. Deviance for the unconditional growth model was -538.72 with 6 estimated parameters. Whether there is a positive or negative deviance, the model is a better fit compared to the previous model if the deviance moves towards zero. With the unconditional growth model, deviance moved farther from zero and became more negative indicating that time did not improve model fit. A summary of deviance and coefficients from the null model and unconditional growth model for walking AVO_2 is found in Table 5. VO_2 increased by 0.04 L/min per year indicated by time (π_1). Slope variance was significant ($p<0.001$), indicating that there was some variation in slope among subjects over time. Since slope variance was significant, a model which included covariates at level-2 for both the slope and intercept level was then run. The covariates for walking AVO_2 were age, gender, and weight (kg). This model with covariates was run to ensure that the fit of the model did not improve when covariates were included. The deviance for this model was -677.80 with 12 estimated parameters. The variance of the slope was still significant ($p<0.001$). However, due to the deviance becoming more negative with the addition of the covariates, further analysis was not warranted. In summary, expressing walking VO_2 in absolute terms did not provide a good model fit due to the small increase in VO_2 each year (0.04 L/min). Figure 4 shows individual trajectories to show small increase in VO_2 over time for all participants. Figure 5 shows average VO_2 (L/min) by age for years 1 for walking.

Figure 4: Walking VO2 (L/min) over time.

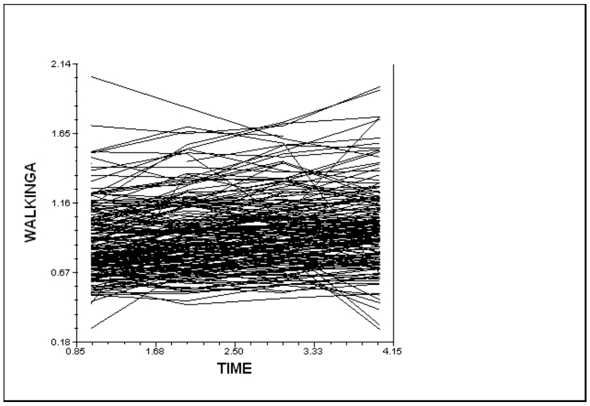


Figure 5: Average VO_2 (L/min) for year 1 by age for walking.

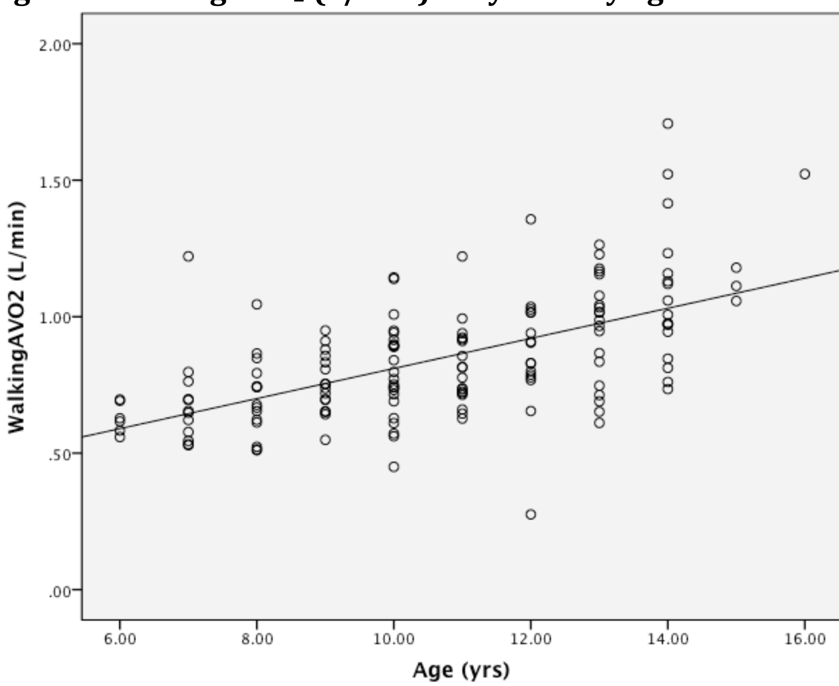


Table 5: Walking Absolute VO_2 (L/min) in youth over time.

Model	**Null Model**	**Unconditional Growth Model**
Variables		
Fixed effects	Estimates	Estimates
Constant (π_0)	0.91±0.02	0.81±0.02
Time (π_1)		0.04±0.01
Random effects	Level-1	Level-1
Constant (e)	0.02±0.12	0.01±0.10
	Level-2	Level-2
Intercept (r_0)	0.05±0.21	0.05±0.22
Slope (r_1)		0.002±0.05
Deviance	-416.17	-538.72
Change in deviance		122.56*
Estimated parameters	3	6

Fixed effects: coefficients ± Standard Deviation (S.D.) (VO_2, L/min)
Random effects: coefficients ± S.D. (VO_2, L/min)
$p<0.05$ if mean > 2 x S.D.
*$p<0.05$ for change in deviance from previous model

Running: Absolute VO_2 (AVO_2; L/min)

A null model was created for running, which included only the dependent variable, VO_2, expressed in absolute terms (L/min). The null model was needed to determine deviance for model comparison and ICC. The deviance for the null model was 438.72 with 3 estimated parameters. ICC was calculated (0.23/(0.23+0.06)) as 0.79 (or 79%) indicating HLM was appropriate for analysis. A summary of deviance and coefficients for running AVO_2 are found in Table 6. Using deviance from the null model, an unconditional growth model was run with time in the level-1 model. Deviance for the unconditional growth model was 181.16 with 6 estimated parameters. The fact that deviance moved closer to 0 from the null model to the unconditional growth model indicated model fit improved with the addition of time at level-1. Absolute VO_2 increased by 0.13 L/min per year and variance for slope was significant ($p<0.001$), which indicated the slope of the line (change in VO2) varied among subjects. Since deviance compared between models indicated that the addition of time improved model fit and because there was significant variance in slope among participants, it was appropriate to add predictor variables to level 2.

Using deviance from the unconditional growth model to compare model fit, each predictor variable was entered into the level-2 model at the slope and intercept level independently. Predictor variables for this model were maturity, BSA, LL, REE, SF, percent body fat, and VE. This was done to determine the effect that a predictor variable had on slope variance independently and whether or not it was a significant predictor. None of the predictor variables were found to be significant for slope at level-2 ($p>0.05$). This showed that even though there was slope variance among participants, none of the predictor variables were able to explain this variance. Covariates CA (grand mean centered), gender, and weight were then entered into a model at the slope and intercept level of the level-2 model. In the final estimation of fixed effects (with robust standard errors) table, gender was significant at the slope level ($p=0.006$) but CA ($p=0.598$) and weight ($p=0.162$) were not. Slope variance decreased from 0.004 in the unconditional model to 0.003 in the model with the covariates. However, slope variance was still significant ($p<0.001$) indicating not all of the change in slope was explained by the predictor variables. Since none of the predictor variables were significant independently, further analysis was not needed. With the available predictor variables and covariates, it was not possible to completely explain the significant variance in slope for running VO_2 (L/min). Thus, absolute VO2 increased by 0.13 L/min per year. In the final model, controlling for other variables, being female lowered VO_2 by 0.05 L/min per year. Figure 6 shows average VO_2 (L/min) by age for years 1 for running.

Figure 6: Average VO2 (L/min) for year 1 by age for running.

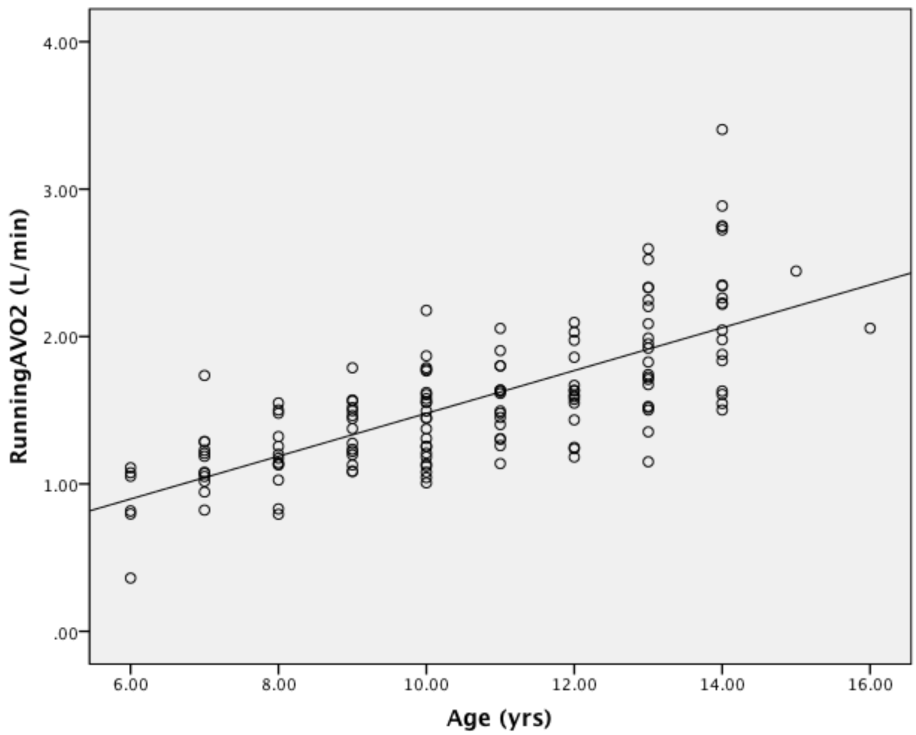


Table 6: Running Absolute VO_2 (L/min) in youth over time.

Model	Null Model	Unconditional Growth Model	Model with Covariates
Variables			
Fixed effects	Estimates	Estimates	Estimates
Constant (π_0)	1.78±0.04	1.45±0.04	0.62±0.13
Gender			-0.15±0.04
CA			0.05±0.01
Weight			0.03±0.003
Time (π_1)		0.13±0.009	0.25±0.05
Gender			-0.05±0.02^
CA			0.003±0.006
Weight			-0.001±0.001
Random effects	Level-1	Level-1	Level-1
Constant (e)	0.06±0.25	0.03±0.17	0.03±0.17
	Level-2	Level-2	Level-2
Intercept (r_0)	0.23±0.48	0.47±0.22	0.02±0.14
Slope (r_1)		0.004±0.06	0.003±0.05#
Deviance	438.72	181.16	-49.01
Change in deviance		257.56*	230.17*
Estimated parameters	3	6	12

Fixed effects: coefficients ± Standard Deviation (S.D.) (VO_2, L/min)
Random effects: coefficients ± S.D. (VO_2, L/min)
^p<0.05 if 2 x S.D. for predictor variables of slope
#Slope remained significant in the final model (p<0.05)
*p<0.05 for change in deviance from previous model

Walking: Relative VO_2 (RVO_2; ml/kg/min)

The null model for walking, which included only the dependent variable VO_2 (ml/kg/min), was run to determine deviance for model comparison and ICC. The null model produced a deviance of 3192.59 with 3 estimated parameters. ICC was calculated as (9.20/(9.20+8.46)) 0.51 (or 51%). Using deviance from the null model, an unconditional growth model, which included time at level 1, was run. The unconditional growth model produced a deviance of 3008.71 with 6 estimated parameters indicating that model fit improved with the addition of time in the model. Slope variance (0.87±0.94) was also significant ($p<0.001$) indicating there was individual variation in slope among participants. The unconditional growth model further indicated that VO_2 decreased by 1.19 ml/kg/min per year. Since deviance improved (indicating a better model fit from the null model to the unconditional growth model) and slope variance was significant, further analysis was needed to determine which predictor variables influenced the change in slope. A summary of model analyses for Walking RVO_2 can be found in Table 7.

Each predictor variable was then entered into the model at the slope and intercept level for the level-2 model. Predictor variables included maturity, REE, BSA, LL, SF, Percent Body Fat (BF), and VE. Maturity (0.68±0.21), REE (-0.29±0.06), BSA (1.98±0.39) LL (0.06±0.01), BF (0.03±0.01), and SF (-0.16±0.04) were found significant at the slope level of the level-2 model while VE (-0.01±0.03) was not. Using deviance from the unconditional growth model, a model with the covariates CA (grand mean centered) and gender was run. In this covariates model, deviance was 2964.05 with 10 estimated parameters. Using this deviance from the covariates model, the predictor variables that were found significant independently (Maturity, REE, BSA, LL, BF, and SF) were entered into separate models to determine if they were still significant in a model that included CA and gender at the slope and intercept level of the level-2 model. BSA (2.27±0.67), REE (-0.23±0.08), LL (0.05±0.02), and SF (-0.11±0.06) were found significant while maturity (0.45±0.27), BF (0.02±0.01), and VE (-0.06±0.03) were not. BSA, REE, LL, and VE were then run in a model together with the covariates age and gender to produce the final model of best fit for walking RVO_2 (ml/kg/min). BSA and VE were significant in the final model ($p<0.05$) but REE and LL were not. CA was also significant while gender was not ($p<0.05$). Thus, VO_2 decreased by 1.19ml/kg/min per year. In the final model, with every one-unit change in VE (L/min) and CA (years), VO_2 (ml/kg/min) decreased by 0.15ml/kg/min and 0.14, respectively. For every one-unit change in BSA (m^2), VO_2 increased by 4.22 and 0.03ml/kg/min, respectively. However, slope variance remained significant in the final model, meaning the predictor variable were not able to explain all the difference in slope among participants. Figure 7 shows average VO_2 (ml/kg/min) by age for years 1 for walking.

Figure 7: Average VO_2 (ml/kg/min) for year 1 by age for walking.

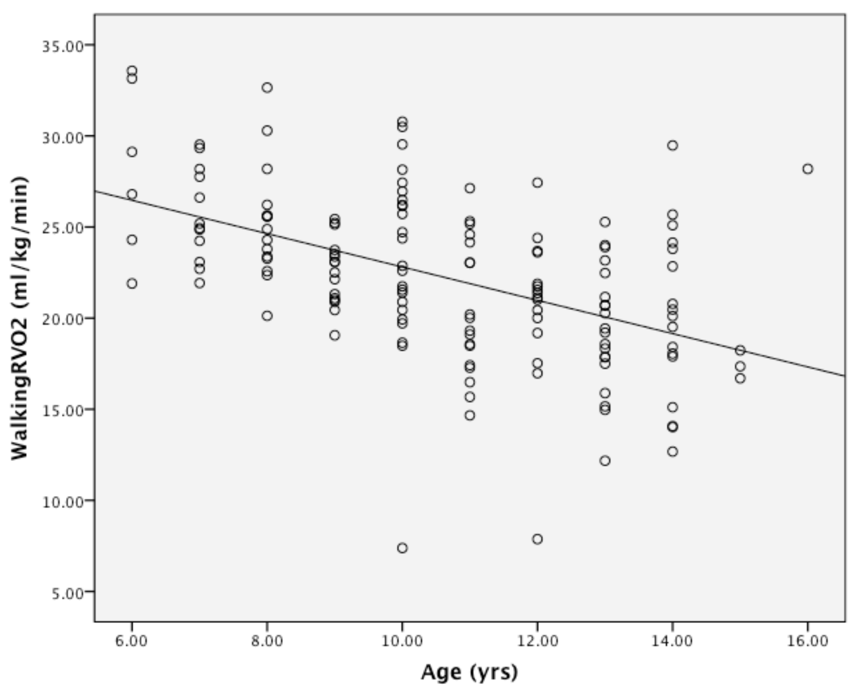


Table 7: Walking Relative VO_2 (L/min) in youth over time.

Model	Null Model	Unconditional Growth Model	Model with covariates	Final model
Variables				
Fixed effects	Estimates	Estimates	Estimates	Estimates
Constant (π_0)	20.51±0.28	23.47±0.45	25.49±1.17	45.00±4.36
Gender			-1.33±0.79	0.45±0.56
CA			-1.00±0.19	0.67±0.20
BSA				-21.32±2.20
LL				-0.21±0.05
VE				0.78±0.09
REE				0.28±0.24
Time (π_1)		-1.19±0.11	-1.18±0.31	-4.76±1.62
Gender			-0.001±0.21	-0.32±0.21
CA			0.16±0.05	-0.14±0.07^
BSA				4.01±0.81^
LL				0.03±0.02
VE				-0.14±0.03^
REE				-0.05±0.09
Random effects	Level-1	Level-1	Level-1	Level-1
Constant (e)	8.46±2.91	4.67±2.16	4.67±2.16	4.66±2.16
	Level-2	Level-2	Level-2	Level-2
Intercept (r_0)	9.20±3.03	23.12±4.81	16.55±4.07	1.50±2.24
Slope (r_1)		0.87±0.94	0.72±0.85	0.28±0.53#
Deviance	3192.59	3008.71	2964.05	2846.18
Change in deviance		183.88*	44.66*	117.8*
Estimated parameters	3	6	10	16

Fixed effects: coefficients ± Standard Deviation (S.D.) (VO_2, ml/kg/min)
Random effects: coefficients ± S.D. (VO_2, ml/kg/min)
^p<0.05 if 2 x S.D. for predictor variables of slope
#Slope remained significant in the final model (p<0.05)
*p<0.05 for change in deviance from previous model

Running: Relative VO_2 (RVO_2; ml/kg/min)

The null model, which included on the dependent variable VO_2, was run to determine deviance (for model comparison) and ICC to ensure HLM was the appropriate statistical analysis. The null model for running RVO_2 produced a deviance of 3532.93. ICC was calculated as 0.58 or 58%, indicating HLM was appropriate. An unconditional growth model was then run, which included VO_2 and time at level 1. Using deviance from the null model, the unconditional growth model was run to determine if model fit improved with the addition of time and if there was individual variation in slope among participants. Deviance for the unconditional growth model was 3501.02 (model fit improved) and variance of the slope was significant ($p=0.008$) indicating individual variation in slope and future analysis was warranted. VO_2 was found to decrease by 0.87 ml/kg/min per year. A summary of model analyses for Running RVO_2 can be found in Table 8.

Each predictor variable was then entered into a model independently at the slope and intercept level of level 2. Predictor variables for running RVO2 were maturity, BSA, REE, LL, BF, SF, and VE. Maturity (0.80±0.33), BSA (1.47±0.63), and LL (0.08±0.02) were significant. REE (-1.78±0.13), BF (0.03±0.02), SF (-0.04±0.05), and VE (0.02±0.01) were not significant. Still using deviance from the unconditional growth model, a model with the covariates CA and gender were entered into the model at the intercept and slope level of the level-2 model. The model with covariates produced a deviance of 3571.70 and slope variance remained significant. Predictor variables that were found significant independently (Maturity, BSA, and LL) were then separately entered into the model with covariates at both the slope and intercept level. LL (0.07±0.03) remained significant in a model with the covariates while maturity (0.65±0.45) and BSA (1.73±0.97) were not. Thus, VO2 decreased by 0.87 ml/kg/min per year. LL was the only predictor variable at the slope level that was significant in the final model ($p=0.048$). For every unit increase in LL (cm), VO2 increased by 0.07ml/kg/min. Slope variance remained significant in the final model, meaning LL did not explain all the variance in slope among participants (p=0.049). Table 9 is a summary of all HLM models that indicates amount of change over time, significant predictors, and significance of the final model. Figure 8 shows average VO_2 (ml/kg/min) by age for years 1 for running.

Figure 8: Average VO_2 (ml/kg/min) for year 1 by age for running.

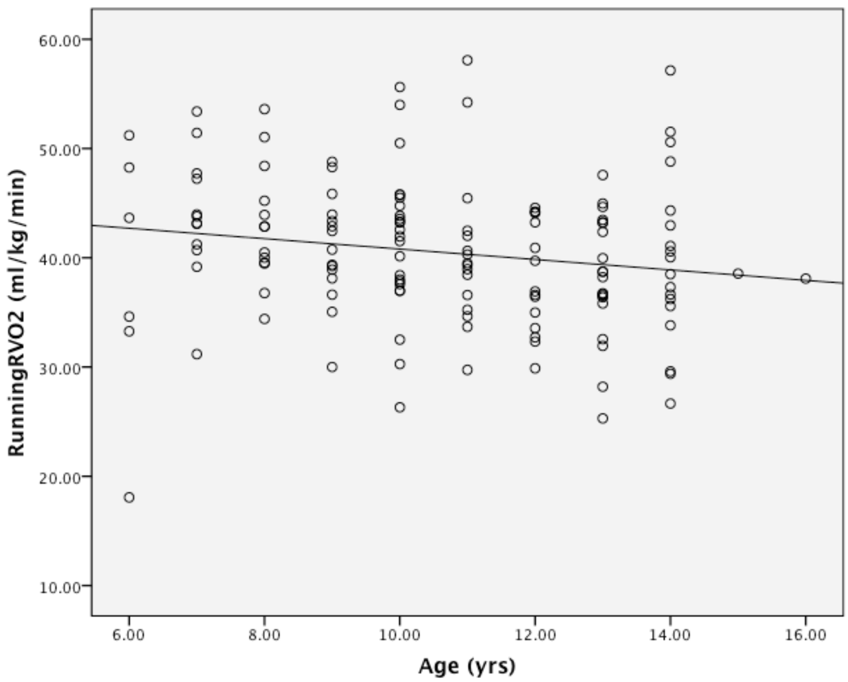


Table 8: Running Relative VO_2 (L/min) in youth over time.

Model	Null Model	Unconditional Growth Model	Model with covariates	Final model
Variables				
Fixed effects	Estimates	Estimates	Estimates	Estimates
Constant (π_0)	39.34±0.47	41.52±0.66	49.59±1.96	78.42±7.13
Gender			-5.44±1.22	-4.15±1.17
CA			-0.44±0.28	0.69±0.35
LL				-0.44±0.10
Time (π_1)		-0.87±0.17	-1.42±0.55	-5.77±2.32
Gender			0.37±0.34	0.17±0.34
CA			0.11±0.09	-0.06±0.12
LL				0.07±0.03^
Random effects	Level-1	Level-1	Level-1	Level-1
Constant (e)	19.16±4.38	16.50±4.06	16.50±4.06	16.50±4.06
	Level-2	Level-2	Level-2	Level-2
Intercept (r_0)	27.01±5.20	36.18±6.02	27.42±5.23	20.95±4.58
Slope (r_1)		0.84±0.91	0.85±0.72	0.57±0.76#
Deviance	3532.93	3501.02	3571.70	3552.05
Change in deviance		31.91*	29.32*	19.65*
Estimated parameters	3	6	10	12

Fixed effects: coefficients ± Standard Deviation (S.D.) (VO_2, ml/kg/min)
Random effects: coefficients ± S.D. (VO_2, ml/kg/min)
^p<0.05 if 2 x S.D. for predictor variables of slope
#Slope remained significant in the final model (p<0.05)
*p<0.05 for change in deviance from previous model

Table 9: Summary of results for walking and running.

Model	Slope (change in VO_2 over time)	Significant Predictors	Slope for final model
Walking (L/min)	+0.04	N/A	N/A
Running (L/min)	+0.13	Gender	Significant
Walking (ml/kg/min)	-1.19	VE, CA, BSA	Significant
Running (ml/kg/min)	-0.87	LL	Significant

Discussion

The purpose of this study was to examine change in economy (VO_2) over a four-year time period and determine factors that predicted change in economy for walking and running in children and adolescents. A novel concept of this study was the longitudinal design and simultaneous understanding of VO_2 and factors. HLM models were created with the dependent variable, VO_2, expressed in absolute terms (L/min) and relative terms (ml/kg/min). Economy has traditionally been expressed in the literature as VO_2 ml/kg/min[2, 3]. However, there has been recent debate over the best way to scale and express VO_2 [14, 33]. Creating a HLM model with VO_2 expressed in absolute terms and controlling for weight (kg), is an approach that is similar to ratio scaling (modeling as ml/kg/min). It is still possible that allometric scaling may be a better approach. However, that would require separate scaling factors be created for each activity.

Absolute VO_2 models

In this study, absolute VO_2 increased per year by 0.04±0.22 L/min for walking and 0.13±0.009 L/min for running. Becoming more economical is indicated by a decrease in VO_2 when expressed in ml/kg/min[2, 3]. Including weight (kg) as a covariate in the walking and running HLM models could have allowed for examination of change in economy just as if VO_2 were expressed in ml/kg/min. However, this was not the case. For walking, model fit did not improve with the addition of time. This is likely due to the small increase in VO_2 over four years (0.04 L/min per year). Since there was no change over time, further analysis was not warranted. Slope variance, although significant, was very small (0.002±0.05 L/min), meaning that there was very little variation in slope among individuals. For running, model fit improved when time was added to the model, indicating there was change in VO_2 over the four years. However, none of the predictor variables added to the model were significant. Gender, which was included in the model as a covariate, was significant. Girls (coded in HLM as 1) were less economical than boys (coded in HLM as 0) in this study. There is some evidence in the literature to suggest gender is a factor related to economy with girls being more economical than boys[5, 9, 15, 16]. However, with a slope variance of 0.003±0.05 L/min, although significant, there was very little difference to explain among individuals. It is more likely the case that expressing VO_2 in absolute terms (L/min) is not appropriate for examining change in economy even when weight is a covariate in the model.

Relative VO_2 models

Morgan et al. measured VO_2 in children annually from 6 to 10 yrs[23]. They found VO_2 decreased on average by 1.0 ml/kg/min per year when children walked at 3.5mph, which is similar to speed in the current study[23]. Ariens et al. found VO_2 decreased by 5 ml/kg/min from age 13-16 when boys and girls ran on a treadmill (5mph) annually[5]. In the current study, the decrease in VO_2 is similar to that found by Morgan[23]. VO_2 decreased by 1.19±0.11 ml/kg/min per year for walking. The decrease in running VO_2 in this study was less (0.87±0.18 ml/kg/min per year) than that found by Ariens et al. This difference could be due to the first year's self-selected pace in the current study, age of the participants, or running over ground versus on a treadmill. For both walking and running, as expected, VO_2 (ml/kg/min) decreased over time similar to other studies examining longitudinal changes in economy[5, 13, 23].

Walking RVO_2 had the most predictors (BSA, CA, and VE). At rest, as explained by the Surface Law, smaller animals per unit weight have greater heat production and oxygen uptake compared to larger animals[36]. Due to the greater oxygen uptake, BSA has been identified as a factor related to inferior economy in children. This is plausible during rest. Bar-Or found a difference in resting energy expenditure of 1-2 ml/kg/min between children and adults[7]. The smaller animal, or child, produces more heat, thus expends more energy.

During exercise, the difference in economy between children and adults is greater than the 1-2 ml/kg/min found at rest. Economy can differ by 6-7ml/kg/min during running between children and adults[1]. During exercise, body mass is moved, not body surface area. However, in an attempt to control for body surface area, VO_2 has previously been expressed relative to body surface (ml/m^2/area) instead of the traditional ml/kg/min. Rowland et al. found that when VO_2 was expressed as ml/m^2/min, this eliminated the difference in economy between children and adults indicating differences in economy can be explained, in part, by BSA[2, 3]. However, Maliszewski and Freedson found men had a 13% higher energy cost compared to boys when VO_2 was expressed as ml/m^2/min[1]. In the present study, body surface area was included in the model as a predictor variable instead of expressing VO_2 as ml/m^2/min. For walking, body surface area, with a coefficient of 4.22, explained the majority variance in slope among participants. However, in contrast to previous results, body surface area had no influence on economy during running[2]. While body surface area did not explain all the variance in slope for walking, our results support Rowland's findings, that during exercise, the Surface Law explains some differences in economy.

Traditionally, SF has been linked to children having inferior walking and running economy compared to adults[11]. Children, due to their shorter leg lengths, take more strides than adults at a given walking or running speed. Rowland et al. found VO_2 per stride to be the same between children and adults at three different running speeds[2, 3]. Unnithan et al. found VO_2 per stride was similar between children and young adults[11]. If VO_2 per stride is the same, and children take more strides compared to an adult, than stride frequency should explain why children have inferior economy. In the current study, both stride frequency and leg length were included in the models for walking and running. As expected stride frequency decreased over four years for both walking and running. In contrast to previous literature, stride frequency was not related to change in economy over time. This could be partially due to participants self-selecting their pace in the current study instead of working at an absolute pace used previously[11]. Participants in the current study also only self-selected stride frequency during the first year. This may have been an optimal stride frequency during year 1, but as participants grew and leg length and stride length changed, stride frequency may have not been optimal for subsequent years. Another difference between the current study and previous research is participants in the current study walked overground instead of their steps being driven by the treadmill. Previous research has been limited to treadmill walking and running[2, 3, 11]. Future research should examine differences in stride frequency in children and adolescents when walking and running on a treadmill and overground.

Maliszewski and Freedson (1996) compared running economy between boys and men at a speed relative to leg length[1]. Each participant ran at a relative speed that was equal to 3.71 leg lengths per second. They found that when VO_2 was expressed relative to body mass (kcal/kg/min), there was no difference in economy between boys and men. The current study supports these findings. For running, leg length was a predictor of economy. Previous studies have postulated that stride length or a ratio of stride frequency to stride length explained the inferior economy in children[2, 3]. While stride length cannot be ruled out, as it was not measured in this study, leg length, not stride frequency, explained some of the variation in economy among participants.

Ventilation, or more specifically energy cost of respiration, has previously identified as a difference in economy between children and adults[2-4]. For every liter of oxygen consumed during submaximal exercise, ventilation is higher for children compared to adults[72]. Ventilatory equivalent of oxygen, VE/VO2, decreases with age, therefore suggesting it is related to change in economy[72]. However, VE/VO_2 could not be included in the current study as a predictor variable since VO_2 was the outcome variable. Rowland et al. found children have a higher respiratory rate and ventilation compared to adults[2, 3]. Allor et al. found girls have a higher respiratory rate and ventilation compared to women when matched for body weight and height[4]. Rowland et al. found tidal volume per body weight (ml/kg x 10^2) is lower in children compared to adults[3]. While respiratory rate was not measured in this study, based on previous literature, it is likely the reason why ventilation influenced the change in economy for walking and running. Dempsey et al. found the cost of VE accounts for only a small portion of total VO_2 (3-5%)[73]. Based on the small regression coefficient found for VE (-0.15±0.03) for walking (VO_2 ml/kg/min) and the small cost VE found by Dempsey et al., VE explains some of the difference in economy over time in children and adolescent but not all. It is also possible that VE in this study is an indirect marker for children's higher sensitivity to CO_2 during exercise[74, 75]. Future research should examine specific components of VE (respiratory rate, tidal volume), VE/VO2, and CO_2 sensitivity during exercise in children and adolescents to determine the exact mechanism that influences economy.

Maturation has recently been considered as a factor related to economy in youth. Few studies have examined maturation related to economy[14, 32, 33] and of those only one study found maturation explained differences in economy[14]. Similar to previous results, maturity status was not a predictor of change in economy when controlling for CA in this study. Similar to the study by Spencer, age at peak height velocity (APHV) was used to determine maturity status. However, in the current study participants were classified as pre-APHV or post-APHV instead of early, average, or late maturers. There were not enough participants in the early (boys = 17; girls = 15) and late (boys = 15; girls = 3) categories compared to the average category (boys = 63; girls = 88) to run the analyses with three groups.

In the final models of best fit (VO_2 ml/kg/min), slope variance was still significant for both walking (0.23±0.48; p=0.010) and running (0.57±0.76; p=0.049).

This means, with the predictor factors entered into the models, we were unable to explain all of the variance among individuals in regards to slope. There may be other factors related to economy that were not measured in this study that could explain the remaining slope variance. Frost et al. found cocontraction of agonist and antagonist muscles was higher in younger children (7-8 years old) compared to older children (10-12 years old) resulting in a higher metabolic cost in the younger children[12]. Optimal stride length during running was not calculated due to participants walking and running around a course in the gymnasium. While deviating from optimal stride length is only thought to make a small difference in VO_2 (0.2ml/kg/min)[54], this could explain some of the variance for running in this study. We were also unable to control for stride dynamics, which are thought to develop at different times in children and could influence economy[55]. The development of a mature running pattern and gait progresses differently from child to child[76]. Wickstrom has identified a number of factors that differ between a child and adult during running, which could be related to economy[76]. These factors include differences in vertical displacement, time in the nonsupport phase, and placement of the support foot. The current study did not include any factors related to gait development except stride frequency. Factors related to the development of a child's gait as s/he ages should be considered in future studies related to economy.

There were strengths related to with this study. The majority of studies related to economy are cross-sectional. This was a mixed longitudinal study where participants were followed for four years. Participants in the current study walked overground instead of on a treadmill. The majority of previous research examining economy required participants to walk on run on a treadmill[2, 3, 5, 23]. Walking on a treadmill requires less energy than walking overground[58]. By having participants walk overground, this mimics what they actually do on a daily basis. Another strength of this was participants included both males and females instead of only one gender. The current study had a wide age range (6-16 year 1). Another strength of this study was including many predictor variables in the HLM models, which has not been done previously.

Limitations related to this study include walking and running at a self-selected pace, not including substrate utilization as a predictor variable, and use of the Schofield equation. During the first year, participants self-selected a walking and running pace and completed this same pace for the next three years. In many cases, for running in particular, the pace was too slow for participants in the third and fourth year of data collection. Participants, therefore, may have been running at a pace that was not optimal, resulting in a greater stride frequency and metabolic cost (and hence, poorer economy). However, since pace was self-selected during year 1, it could not be changed for years 2-4. Another limitation was not including any measure of substrate utilization in this study. In a study comparing validity of metabolic measures, VCO_2 measured by the Oxycon was not valid compared to the criterion measure (Douglas bags)[77]. Therefore, we were unable to calculate RER (VCO_2/VO_2) and include a measure of substrate utilization in the HLM models.

In summary, expressing VO_2 in absolute terms (L/min) was not appropriate for examining change in economy and predictors of change even when controlling for CA, weight, and gender. When VO_2 was expressed in relative terms (ml/kg/min),

VO_2 decreased over time for both walking and running. For walking, CA, BSA, and VE were significant predictors of change in economy. LL was the only predictor variable found for running. However, not all the variance in slope among participants could be explained by the predictor variables in this study. Future research should further explore VE as a predictor variable and examine other predictor variables not included in this study to explain the remaining variance in slope.

CHAPTER 4

LONGITUDINAL CHANGES IN ENERGY EXPENDITURE DURING FOUR LIFESTYLE ACTIVITIES IN CHILDREN AND ADOLESCENTS

Abstract

Examining change over time in energy expenditure in children and adolescents has been limited to standardized laboratory-based methods of running, walking, and cycling. Previous studies have found weight-relative energy expenditure (ml/kg/min) decreases in these activities with chronological age (CA) for walking and running. It is unknown whether a similar decrease is seen during lifestyle activities and what factors influence this change. **PURPOSE:** To determine change in energy expenditure during laundry, dance aerobics, sweeping, and basketball over four years and identify factors that associates with change in energy expenditure when expressed as absolute (L/min) and relative (ml/kg/min) oxygen consumption (VO_2) in children and adolescents. **METHODS:** Participants age 6-16 (N=223; 116=males, 107=females) years participated in a mixed longitudinal study. During year 1, participants completed a laundry task, dance aerobics, sweeping, and basketball trial, each lasting five-minutes. Each activity was repeated annually for three consecutive years (years 2-4). Expired gases were collected using indirect calorimetry via a portable metabolic analyzer to estimate VO_2. Hierarchical linear modeling was used to create two separate models (L/min and ml/kg/min) for each activity. Potential influential factors, collected annually, were identified including body surface area (BSA), leg length (LL), resting energy expenditure (REE), percent body fat (BF), maturity, and ventilation (VE). Covariates were age, gender, and weight (L/min only). Significant factors were determined independently using 2 x

SD and then included in a model of best fit. **RESULTS:** Absolute VO_2 increased by 0.04±0.01, 0.05±0.01, 0.008±0.003, and 0.01±0.004 L/min per year for aerobics, basketball, laundry, and sweeping, respectively. For basketball, BSA (0.91±0.45) was significant at the slope level ($p<0.05$). No significant predictor variables were identified for the aerobics, laundry, or sweeping when VO_2 was expressed in absolute terms (L/min). Relative VO_2 (ml/kg/min) decreased by 0.74±0.12, 1.80±0.21, 1.05±0.08, and 1.16±0.09 per year for aerobics, basketball, laundry, and sweeping, respectively. Significant individual variation for VO_2 over time (slope) was found for all four activities ($p<0.05$). For aerobics and basketball, VE was the only significant factor in the final model at the slope level ($p<0.05$). Variance for slope remained significant ($p<0.05$). For laundry and sweeping, VE, BSA, and CA were significant at the slope level ($p<0.05$) and slope variance was no longer significant ($p>0.05$) indicating the predictor variables explained all the variance in slope among participants. **CONCLUSIONS:** Expressing VO_2 in absolute terms (L/min) may not be an appropriate method for identifying factors related to change in energy expenditure. When VO_2 was expressed in ml/kg/min, only VE was identified as a significant influential variable for all four activities. Others factors not included in this study may further explain change over time in energy expenditure for aerobics and basketball in children and adolescents.

Introduction

Understanding change in energy expenditure over time for children and adolescents is important as it influences our ability to accurately predict energy expenditure. This is particularly important as it relates to development of the

Compendium of physical activities for children and adolescents. As more measurement tools are developed to quantify habitual physical activity, it is important to understand how VO_2 changes over time in this population so that methods for estimating energy expenditure can be developed.

In exercise science, economy is defined as the aerobic demand or energy cost required to perform a submaximal exercise task[1]. It is well-founded that children have a greater economy (higher VO_2 ml/kg/min) compared to adults when walking or running[2, 3]. In a cross-sectional study, Rowland et al. found boys use more energy relative to body size to run on a treadmill at a given speed (9.6 kph) compared to men[2]. Similar results were found for girls compared to women[3]. Waters et al. found children have a greater economy compared to adolescents during walking at a self-selected pace[6]. However, the majority of previous literature examining changes in economy between children and adults have been limited to treadmill walking and running.

Beyond walking and running, there are very limited data available on change in economy from childhood to adulthood in other physical activities. In order for comparison of economy between groups, intensity or workload (speed or watts) must remain consistent. When examining physical activities where a set intensity is not set or measured, this is referred to as change in energy expenditure. Rowland et al. examined differences in economy during cycling between boys and men[63]. In this study, no difference was found in economy when the two groups rode at both an absolute and relative intensity. In contrast, Turley et al. found men were more economical when riding at 40 and 60 watts compared to boys[78]. Similar results were found for women. No information is available on change in energy expenditure between children and adolescents or adults participating in other lifestyle physical activities. It is unknown whether energy expenditure decreases similarly to that observed in walking and running during lifestyle physical activities that require multi-planar movement. In this study, four lifestyle physical activities were chosen for analysis: aerobics, laundry, sweeping, and basketball. They were chosen since children and adolescents participate in these physical activities on a regular basis (laundry, sweeping) or they are skill-based activities (aerobics, basketball). In order for energy expenditure and physical activity to be accurately measured in this population, it is important to understand how VO_2 changes in these skill-based activities over time.

For walking and running, a number of factors are thought to influence the difference in energy expenditure in children compared to adults. These factors include, but are not limited to, age[2, 3], resting metabolic rate (RMR)[7, 8], body size[1], gender[9], substrate utilization[10], biomechanics[11, 12], training[13], ventilation[2], and maturation[14]. It is unknown whether the same factors that influence a change in energy expenditure in walking and running influence a change in energy expenditure in lifestyle physical activities. While there are suggestions to support each factor and its influence on the difference in walking and running economy between children and adults, one single factor does not definitively explain why this difference occurs. Hence, it is considered to be multi-factorial. Of all the factors thought to influence economy, body size has been the one most studied. Results on the influences of gender, resting metabolic rate (RMR), percent body fat, leg length, and ventilation on economy are inconclusive.

The primary purpose of this study was to examine longitudinal changes in energy expenditure in four lifestyle activities (laundry, dance aerobics, sweeping, basketball) over four years in children and adolescents. The secondary purpose was to determine factors that influence change in energy expenditure over four years. It was hypothesized that there would be a significant decrease in energy expenditure (relative VO_2) during laundry task, dance aerobics, sweeping, and basketball over the four years. It was further hypothesized that BSA would be a significant predictor of change in energy expenditure and explain the greatest amount of variance. However, maturation, REE, LL, percent body fat, and ventilation would not be significant predictors.

Methods

Participants

Two hundred thirteen participants were recruited to take part in a mixed longitudinal study. Participants were a convenience sample, recruited from two different sites, Michigan State University (n=108) and Oregon State University (n=105), through email, local recreational facilities, and word of mouth. Participants were between 6 and 15 years old during the first visit of year 1. The goal was to have at least five girls and five boys for each age per site. Table 10 shows the number of subjects by year categorized by chronological age and gender.

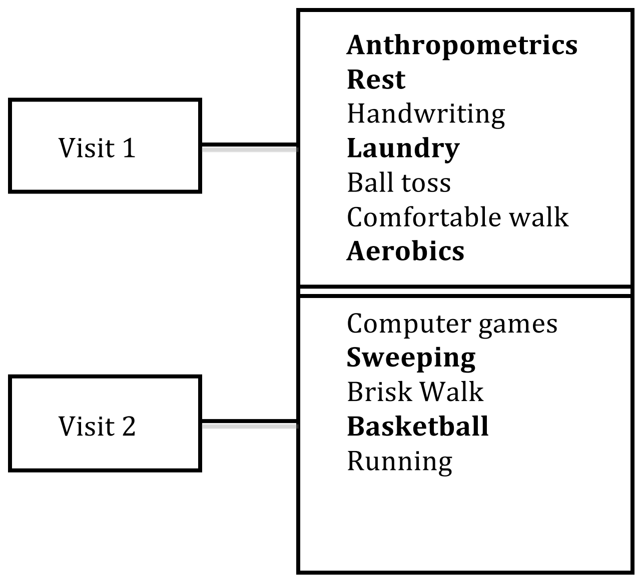
Table 10: Number of subjects by chronological age, gender, and test year.

	Test Years				
Age group (yrs)	Year 1	Year 2	Year 3	Year 4	Total
6	2(4)				2(4)
7	8(4)	2(4)			10(8)
8	7(8)	8(4)	2(4)		17(16)
9	10(7)	7(7)	8(4)	2(4)	27(22)
10	11(14)	10(8)	7(7)	8(4)	36(33)
11	10(8)	11(14)	10(8)	7(7)	38(37)
12	10(6)	10(8)	11(14)	10(8)	41(36)
13	8(14)	10(6)	10(8)	11(14)	39(41)
14	10(7)	8(14)	10(6)	10(8)	38(35)
15	1(3)	10(7)	8(14)	10(6)	29(30)
16	0(1)	1(3)	10(7)	8(14)	19(25)
17		0(1)	1(3)	10(7)	11(11)
18			0(1)	1(3)	1(4)
19				0(1)	0(1)
Total	77(76)	77(76)	77(76)	77(76)	

n=153; Boys (girls)

Each participant attended four visits annually, two individual visits (V1 and V2) and two group visits (V3 and V4) over a three-year period (four time points) at one of the two sites. Participants were subsequently scheduled to return to the laboratory for data collection within 3-month window of the previous year. For the purposes of this study, only data collected from V1 and V2 were used for each of the four years. V1 and V2 were separated each year by approximately 2 weeks. Figure 9 shows which activities were completed each year during V1 and V2.

Figure 9. Flow chart for visits 1 and 2. Repeated for years 1-4.



Bold activities used in this study.

During the initial visit for year one, parents completed a Physical Activity Readiness Questionnaire (PAR-Q), which is a medical history questionnaire, to determine if their children were able to participate. Physical activity requirements for this study were no greater than what children experience during recess or physical education class. Due to this study being part of a larger accelerometry validation study for which participants wore accelerometers during data collection, children were excluded if they had an orthopedic limitation or were in a wheelchair. They were also excluded if they had a medical condition that increased the risk associated with participating in physical activities. Each parent completed a PAR-Q prior to each year of testing to ensure no new medical conditions had occurred over the last year. The two visits each year were separated by at least 24 hours and no more than three weeks. Participants were instructed to not participate in vigorous physical activity the day of testing and to not eat for two hours prior to testing. The institutional review boards at Michigan State University and Oregon State University approved this study. Parental consent and participant assent were received prior to testing at the first visit of each year.

Measures

The different measures assessed during this study include anthropometrics, energy expenditure, and factors related to change in energy expenditure. Anthropometric measures taken in this study were body mass (kg), stature (cm), seated height (cm), and waist circumference (cm). Body fatness was also assessed via skinfolds. Duplicate measures of body mass, stature, and seated height were taken. Waist circumference and skinfolds were taken in triplicate measures. Stature and seated height were measured using wall-mounted stadiometers (Seca 222) to the nearest 0.1cm. For each measurement, the subject's head was positioned in the Frankfurt horizontal plane. If the two measurements were not within 1.0 cm, a third measurement was taken. The two measurements within 1.0 cm were then averaged. Body mass was measured to the nearest 0.1 kg using a Seca portable electronic scale (Seca 770). If the two measurements were not within 0.5 kg, a third measurement was taken. The two measurements within 0.5 kg were then averaged. Measurements of body mass, stature, and seated height were taken without the participant wearing shoes[65]. Waist circumference was measured in accordance with NHANES III protocol[66]. Participants stood with their weight evenly distributed. The research assistant palpated the participant's right hip to find his/her right iliac crest. A horizontal mark with a vertical cross at the midaxillary line was made with a washable marker slightly above the lateral border of the iliac crest. An identical mark was made just above the lateral border of the left iliac crest. A Gulick tape measure was then placed around the participant in line with the two marks and parallel to the ground. A measurement was recorded to the nearest 0.1cm when the participant was at minimal normal respiration. If the three measures were not within 1.0 cm, a fourth measurement was taken. The three measurements within 1.0 cm were then averaged. Using Lange calipers that had been properly calibrated, skinfold measurements were taken at the triceps and medial calf to the nearest millimeter on the right side of the body. Triplicate measures from each skinfold site were taken and an average was computed. If a measure was not within 2mm, a fourth measure at that site was taken and the three measurements within 2mm where averaged.

Energy expenditure was estimated during each submaximal activity by the Oxycon Mobile portable metabolic analyzer (Care Fusion, San Diego, CA). The Oxycon Mobile was calibrated for ambient conditions, volume flow, and gases prior to each subject being tested. Each participant was fitted with a vest, mask, and headgear prior to each visit. A mask was fitted to each participant's face so that there was a seal around the nose and mouth, allowing no air to leak. Headgear was then fitted based on the participant's head size and attached to the mask. A Triple-V from the Oxycon Mobile was then attached to the mask. During a 10-minute pre-exercise rest trial, only the mask and headgear were worn due to the participant lying supine on a mat. After rest, each participant was fitted with a vest. The vest was fitted so that it was tight enough not to move around during the activity trials while not restricting a participant's movement or breathing. The SBx and DEx from the Oxycon Mobile were strapped to the vest on the back of the participant. During each 5-minute trial, metabolic measures included VO_2, VCO_2, VE, and RER (VCO_2/VO_2) and were assessed breath-by-breath by the Oxycon Mobile. The breath-by-breath measurements were then aggregated by 10-seconds. Data reduction consisted of averaging these 10-second values over a two minute time period for each activity. Minutes 2:30-4:30 were used for data analysis for each activity. Heart rate was estimated by telemetry. In the instance that telemetry was lost with the Oxycon, a Polar heart rate watch was then used.

Factors assessed in this study related to changes in energy expenditure included: chronological age, gender, maturation, resting energy expenditure, body surface area (BSA), percent body fat, leg length and ventilation. Test date minus birth date was used to calculate chronological age. Gender was self-reported prior to the first visit year one. Maturation was obtained by calculating predicted age at peak height velocity (APHV) using the equation developed by Mirwald et al.[67]. APHV was calculated for each participant at all four-time points. Due to the age of some participants, only one calculation was found to be valid (within ±4 years of maturity age), therefore that APHV was used. For participants with more than one valid maturity age, the predicted value that was closest to their APHV (closest to a maturity offset of 0) was used. For example, if a participant had two valid APHV calculated over the four time points, the maturity age where the participant was closest to his/her APHV was used (personal communication, Dr. Adam Baxter-Jones). After APHV was determined, each participant was coded as pre-APHV (0) or post-APHV (1) for analysis. Resting energy expenditure (REE) was determined from the 10-minute pre-exercise rest trial. Participants were supine on a mat for 10-minutes while metabolic measures and heart rate were collected via the oxycon mobile. VO_2 collected during minute's 7:30-9:30 was then averaged to determine REE. Weight and height were entered into a gender specific equation to determine REE. Body surface area was calculated for each participant at each visit by using the Haycock equation[68]: BSA (m^2) = 0.024265 x Height(cm)$^{0.3964}$ x Weight(kg)$^{0.5378}$. Leg length was calculated each year by first determining a participants trunk length (standing height-(seated height-height of the stool (73.65 cm). Standing height was then subtracted from trunk length to determine leg length. Percent body fat was determined from calf and triceps skinfolds using the gender specific Slaughter equations for children and adolescents[69].

Procedures

Participants came to the Human Energy Research Laboratory (HERL) at Michigan State University or the Physical Activity Assessment Laboratory (PAAL) at Oregon State University for two visits annually (V1 and V2) over a three-year period. Annual visits for each participant were completed within a +/- 3-month window of when they came to the laboratory the previous year. This resulted in a total of eight visits to the laboratory.

Participants came to the laboratory following a 2-hour fast and refraining from any vigorous physical activity on the day of testing. Figure 5 shows a list of all activities completed during V1 and V2. V1 consisted of six activities: rest, handwriting, laundry, ball toss, comfortable walk, and dance aerobics. For this study, only laundry and dance aerobics were used in the analysis. V2 consisted of six different activities: computer games, sweeping, brisk walking, basketball (shooting hoops), running, and treadmill walking. For this study, only sweeping and basketball were used in analysis.

Upon arrival to the laboratory, anthropometric measures were taken and participants completed the 10-minute rest trial. Participants wore the Oxycon Mobile portable metabolic analyzer (San Diego, CA) to assess metabolic measures (VO_2, VCO_2, VE, RER) throughout each activity. After anthropometric measurements were taken, participants were fitted with a mask and vest for the Oxycon Mobile. The mask was fitted so that no air was leaking, ensuring that all expired air was being analyzed and that the appropriate dead space was set in the Oxycon Mobile program. Participants also wore a heart rate monitor, which sent information via telemetry to the Oxycon Mobile. In the instance that telemetry was lost with the Oxycon, a Polar heart rate watch was then used to obtain heart rate during a trial.

Participants first completed a laundry trial for five minutes. Two tables were placed ten feet apart. Participants picked up a basket of five unfolded towels and walked from one table to the second table. Participants then folded each towel three times and placed it on the table. Once the five towels were folded, participants picked up the empty laundry basket, walked back to the first table, and picked up five more unfolded towels. They repeated this task of folding five towels for five minutes. Prior to the trial, each participant was read a standardized script.

> "For this trial you will be loading up a laundry basket with unfolded towels, carrying it over to this table, dumping the towels out on the table, and then folding them. When folding the towels you should fold them in half three times, but don't worry about doing a good job. After the towels are folded

> leave them on the table. Then you will take the laundry basket back to where you started to retrieve more towels to be carried back to the other table to be folded. This is not a race, just take your time. You will continue to do this for 5 minutes."

Participants then completed a dance aerobics trial for five minutes. During the trial, participants followed an instructor on a pre-recorded DVD and were told to mimic the instructor as closely as possible. Prior to the trial, each participant did a brief (30-60 seconds) dance aerobics practice to ensure s/he would be able to follow along. Each participant was read a standardized script prior to the start of each trial. The same dance aerobics DVD was used for all four years of testing.

> "For the next trial, I want you to follow the instructor on this aerobics DVD. Before we begin, I'd like you to do a practice trial. Do the best you can to follow the instructor, but it is okay if you don't follow it exactly."

Visit 2 consisted of six different activities: computer games, sweeping, brisk walking, shooting hoops, running, and treadmill walking. For this study, sweeping and shooting hoops were used in analysis. Prior to the trial, the Oxycon Mobile was initialized exactly the same for each subject as in the first visit. The sweeping trial consisted of participants sweeping confetti on the floor (5' by 10' box). Prior to the start of the trial, a research assistant spread confetti within the box on the floor. The participant was instructed to sweep all of the confetti from one side of the box to a cone on the other side. A research assistant followed the participant placed more confetti behind him/her on the floor. Once all the confetti was swept to the cone, the participant turned around and swept the newly placed confetti to a cone on the other side of the box followed by a research assistant placing more confetti on the floor. The process was repeated for five minutes until the trial was complete. Prior to the trial, a standardized script was read to the participant.

> "I just spread some Confetti on the floor. I want you to use this broom to sweep the confetti over to one side of the room aiming for the marked box on the floor. As you are sweeping the confetti to one side of the room, I will be putting more confetti down on the floor behind you. Once the confetti is swept to one side of the room, turn around and sweep the additional confetti to the other side of the room aiming for the other marked box. We will continue to do this for 5 minutes."

Each participant then completed a shooting baskets trial for five minutes. A marked course (15' x 15') was set up in the gymnasium and participants were instructed to stay within the designated area. Participants were instructed to continue moving during the entire trial and to chase down any missed shots that stayed in the marked area. If the basketball went outside of this area, a research assistant quickly retrieved the ball and gave it back to the participant. Prior to the start of each trial, each participant was read a standardized script. The same script was read to each participant during all four years of testing.

> "For the next 5 minutes you will be shooting hoops. I would like you to 'shoot hoops' as if you were in your driveway, a neighbor's driveway, or on a playground. Shoot the basketball, get the rebound or chase after it, and shoot it again. While doing this you and the ball must stay within the boundaries (point out boundaries) marked by the cones. If the ball goes outside the boundaries let it go and we will give you another one. It is important that you avoid shooting from the same spot for every shot. Move around within the boundaries and shoot from different spots. You will do this repeatedly for 5 minutes. Do you have any questions?"

Data Reduction

Throughout V1 and V2, the Oxycon Mobile portable metabolic analyzer collected continuous metabolic data breath by breath. The data were then aggregated to 10-seconds. Every activity was five minutes in duration. Minutes 2:30-4:30 were selected for each activity for every participant in the data reduction software specifically designed for this study. The 10-second values from 2:30-4:30 were averaged for all metabolic measures (VO_2 (ml/kg/min), VO_2 (ml/min), VCO_2 (L/min), VE (L/min)) and saved in a database. For analysis, the dependent variable, $VO_{2,}$ was expressed as L/min and ml/kg/min.

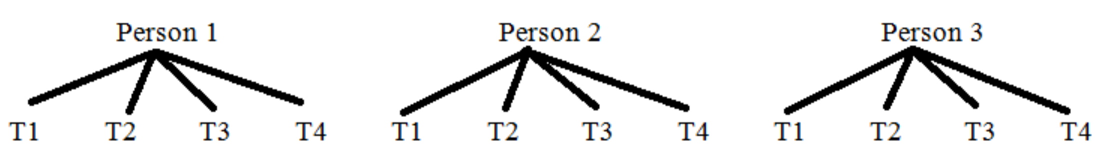
To determine outliers in the data, standard deviations and z-scores were calculated and examined for each variable for each participant. A variable for a participant was deleted if his/her z-score was ±3.. Pearson correlations and variance inflation factors (VIF) from multiple linear regression were used to determine multicollinearity among predictor variables. Multicollinearity was identified if a predictor variables had a VIF greater than 10. In order to compare models in Hierarchical Linear Modeling (HLM), models must be completely nested. This means that if a participant was missing one variable (i.e. VO2 at one time point or APHV), all data for that participant were deleted.

Analysis

The analytical plan for this study involved descriptive statistics and hierarchical linear modeling (HLM) (Aims 1 and 2) to determine longitudinal changes in energy expenditure and time varying and time invariant factors that influenced changes in energy expenditure in children and adolescents. It is accepted that a power analysis for HLM is generally not conducted[70]. The corresponding hypotheses from Aims 1 and 2 were tested together in one model (e.g., Aim 1 Hypothesis 3 were tested simultaneously with Aim 2 Hypothesis 3). The first hypothesis in each pairing examined longitudinal changes in energy expenditure and the second determined factors that influenced change in energy expenditure over time.

Growth curve analysis using HLM was used for Aims 1 and 2. Two analyses were run for each activity with absolute VO_2 (L/min) as the dependent variable in one model and relative VO_2 (ml/kg/min) in the second model. For each analysis, the level 1 model was a repeated measure of time (four years); the level 1 model identified how VO_2 changed over the four years. This represented the change we anticipated each participant to have over the four years in this study (within-person change over time). The level 2 model assessed individuals; the level 2 model identified independent variables that influenced how the dependent variable (VO_2) changed over time. This represented relating identified predictors to inter-individual differences to change (between-person change over time). Figure 6 is a graphical example of level 1 (time) and level 2 (individual) models in a growth curve analysis.

Figure 10: Different levels in a growth curve analysis.



The following analyses were separately performed:

Analysis 1: Aim 1 Hypothesis 3 and Aim 2 Hypothesis 3 assessed longitudinal change and predictors of laundry task energy expenditure.

Analysis 2: Aim 1 Hypothesis 4 and Aim 2 Hypothesis 4 assessed longitudinal change and predictors of aerobics energy expenditure.

Analysis 3: Aim 1 Hypothesis 5 and Aim 2 Hypothesis 5 assessed longitudinal change and predictors of sweeping energy expenditure.

Analysis 4: Aim 1 Hypothesis 6 and Aim 2 Hypothesis 6 assessed longitudinal change and predictors of basketball energy expenditure.

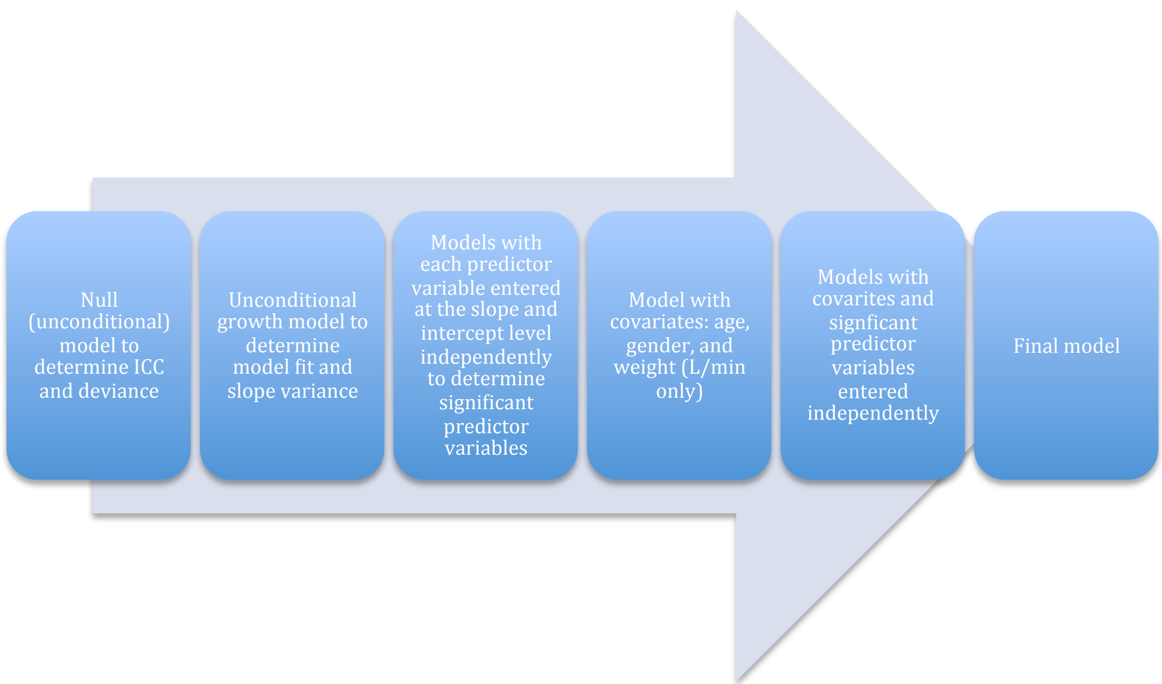
Using HLM, a null (unconditional) model, which included only the dependent variable, VO_2, was run for both absolute (L/min) and relative (ml/kg/min) VO_2 ($Y_{ti} = \pi_{0i} + \pi_{1i} + e_{ti}$). The purpose of this model was to determine deviance (-2 log likelihood) and number of parameters for model comparison. Full maximum likelihood was selected. The inter-class correlation (ICC) was also calculated from the null model. ICC varies from -1 to +1. When ICC is close to 0 or negative, there is large within group variance but little group mean difference and using HLM is not appropriate. HLM is appropriate when ICC is close to +1. There is then a large group mean difference but little within group variance. Using deviance and number of parameters from the null model, an unconditional growth model was run. The unconditional growth model included the dependent variable, VO2, and time (uncentered) in level 1 ($Y_{ti} = \pi_{0i} + \pi_{1i}TIME_{ti} + e_{ti}$). Time was coded as 1 (year 1), 2 (year 2), 3 (year 3), and 4 (year 4). The error term associated with the slope was also included (r_{1i}). Comparison between the null model and the unconditional growth model allowed for determining if the unconditional growth model was a better fit than the null model and if there was variance between individuals in the slope of the line. If there was no variance in the slope, there was no difference between individuals and predictor variables were not needed. If the model did not improve (deviance moves farther away from 0), the addition of time to the model did not improve the model fit, meaning there was no change in slope over time (non-linear model). A null model and unconditional model were run for aerobics VO2 (L/min and ml/kg/min), basketball VO2 (L/min and ml/kg/min), laundry VO2 (L/min and ml/kg/min), sweeping VO2 (L/min and ml/kg/min). If model fit improved from the null model to the unconditional model, and variance of the slope was significant (did not equal 0), further analysis took place.

Using deviance and number of parameters from the unconditional growth model, predictor variables were entered one at a time in level 2 as fixed effects (β), both at the intercept (π_{0i}) and slope (π_{1i}), to determine the independent effect of each predictor variable. Predictor (independent) variables included BSA, maturity, REE, LL, percent body fat, and VE. These predictor variables were also considered predictors of the intercept, meaning they may have caused the starting point of the intercept to change, and were incorporated into the model at the intercept (π_{0i}) for this reason.

For aerobics, basketball, laundry, and sweeping absolute and relative VO2, a model was then run that included all covariates using deviance and number of parameters from the unconditional growth model. Covariates for the absolute VO2 models included chronological age (CA), weight, and gender. Covariates for the relative VO2 models included CA and gender.

Gender and maturity were categorical variables while CA, weight, LL, BSA, percent body fat, REE, and VE were continuous variables. Gender was a time invariant variable (i.e., did not change over time). CA, weight, LL, maturity, BSA, percent body fat,, REE, and VE were time varying variables (i.e., they change over time). Each significant predictor variable found in the previous models was then entered one at a time into the model that included the covariates. Significant predictor variables were identified at the slope level of level 2 ($p<0.05$). To determine the model of best fit, all significant predictor variables identified in the model that included the covariates were entered into a final model at the intercept and slope at level 2. A final model was created for aerobics (L/min and ml/kg/min), basketball (L/min and ml/kg/min), laundry (L/min and ml/kg/min), and sweeping (L/min and ml/kg/min). Figure 7 is a flow chart of the analytical plan for HLM.

Figure 11: HLM analytical plan



Results

In year 1, two hundred thirteen participants were recruited for this study. Twenty-seven participants did not complete all four years of data collection, leaving 186 participants for data analysis. HLM analysis requires participants have nested data. This means that there are no missing values for a participant across the four years of data collection. If a participant was missing any data point, for example VO_2 for the laundry activity for year 2, that participant was completely removed from data analysis for that activity. Participants were also excluded if calculated z-scores for outcome variables or predictor variables were greater than or less than 3. Ten subjects were excluded due to outliers, leaving 176 participants. Table 11 shows how many participants were removed from each physical activity prior to analysis. For aerobics (L/min and ml/kg/min), 25 subjects were excluded for having missing data (not nested), leaving 151 participants. For basketball (L/min and ml/kg/min), 27 subjects were excluded for having missing data, leaving 149 participants. For laundry (L/min and ml/kg/min), 23 subjects were excluded for having missing data, leaving 153 participants. For sweeping (L/min and ml/kg/min), 27 subjects were excluded for having missing data, leaving 149 participants. Table 12 shows descriptive characteristics for the total sample. Table 13 shows average heart rate for minutes 2:30-4:30 for each activity for each of the four years. Heart rate was significantly different across the four years for all physical activities.

Table 11: Participants removed from analyses for aerobics, basketball, laundry and sweeping.

Physical Activity	Participants that did not complete all four years	Participants with missing data	Participants with outliers by z-score	Total number of participants
Aerobics	27	25	10	151
Laundry	27	23	10	153
Sweeping	27	27	10	149
Basketball	27	27	10	149

Table 12. Descriptive characteristics and predictor variables by year.

	Year 1	Year 2	Year 3	Year 4
CA (yrs)	10.6±2.4	11.7±2.4	12.6±2.4	13.6±2.5
BSA (m^2)	1.26±0.27	1.35±0.27	1.44±0.26	1.52±0.26
LL (cm)	69.8±8.7	74.5±9.0	75.7±9.1	77.9±8.8
Height (cm)	144.6±14.8	150.5±14.8	155.3±14.2	159.7±13.2
Weight (kg)	40.3±13.5	44.5±13.4	48.5±13.3	52.8±14.0
REE (ml/kg/min)	6.1±1.6	5.4±1.4	5.2±1.3	5.0±1.2
BF (%)	21.8±7.0	24.2±8.5	22.8±7.4	23.5±7.4
BMI Percentile	64.9±28.9	64.0±28.5	63.9±28.0	62.9±29.0
Aerobics VE (L/min)*	19.4±5.7	20.1±5.7	20.7±6.0	30.0±5.8
Basketball VE (L/min)*	33.7±9.4	36.7±10.2	36.1±10.0	33.9±12.2
Laundry VE (L/min)*	14.1±3.0	14.0±3.1	14.0±2.6	14.0±2.8
Sweeping VE (L/min)*	16.6±3.8	16.8±3.6	16.8±3.2	16.3±3.6

n=153 *Aerobics n=151; Basketball n=149; Laundry n=153; Sweeping n=149

Table 13: Average heart rate (HR) for years 1-4 for each activity.

	Year 1	Year 2	Year 3	Year 4
Aerobics HR (bpm)	120.8±15.3*	115.6±18.1	113.6±17.5	111.4±15.1
Basketball HR (bpm)	161.4±19.4*	159.5±19.0	153.0±19.6	142.7±20.8
Laundry HR (bpm)	109.9±13.1*	105.4±14.2	102.0±12.6	98.1±12.7
Sweeping HR (bpm)	117.7±14.8*	111.1±13.5	111.0±14.3	106.0±13.5

*HR significantly different across years 1-4.

Pearson correlations and VIF from multiple linear regression were run to determine multicollinearity among predictor variables. Correlation coefficients are in Table 14. A VIF of 10 for a predictor variable indicates multicollinearity. Using multiple linear regression, all predictor variables for year 1 were entered into the model with VO_2 as the dependent variable. None of the predictor variables had a VIF over 10. Therefore, there was no multicollinearity among predictor variables and all variables were entered into the HLM models.

Table 14: Pearson correlations among predictor variables.

	CA	BSA	LL	REE	Weight	BF%	AeroVE	BballVE	LaundVE	SweepVE
CA	-	0.80	0.73	0.74	0.73	0.32	0.66	0.49	0.39	0.25
BSA	0.78	-	0.76	0.98	0.99	0.62	0.79	0.60	0.56	0.48
LL	0.73	0.76	-	0.70	0.73	0.28	0.60	0.39	0.42	0.46
REE	0.74	0.98	0.70	-	0.98	0.60	0.76	0.66	0.60	0.45
Weight	0.73	0.99	0.73	0.98	-	0.78	0.78	0.59	0.56	0.43
BF%	0.32	0.62	0.28	0.60	0.78	-	0.47	0.28	0.40	0.28
AerobicsVE	0.66	0.79	0.60	0.76	0.78	0.47	-	0.60	0.58	0.52
BasketballVE	0.49	0.60	0.39	0.66	0.59	0.28	0.60	-	0.58	0.58
LaundryVE	0.39	0.56	0.42	0.60	0.56	0.40	0.58	0.58	-	0.66
SweepingVE	0.25	0.48	0.46	0.45	0.43	0.28	0.52	0.58	0.66	-

All correlations were significant ($p<0.001$).

HLM was used to create models of best fit to determine change in VO_2 over the four years and identify predictor variables that influenced this change in VO_2 for all four lifestyle activities. Two models were created for aerobics, basketball, laundry, and sweeping. The first model for each activity included the outcome variable expressed as absolute VO_2 (L/min) and the second model for each activity with the outcome variable expressed as relative VO_2 (ml/kg/min).

Aerobics: Absolute VO_2 (AVO_2; L/min)

A null model, which included only the dependent variable, VO2 (L/min), was first created. The null model was used to determine deviance (-2 log likelihood), which was used to compare model fit, and to calculate the intraclass correlation (ICC). ICC determined if multilevel modeling such as HLM was needed. ICC ranges from -1 to 1. When ICC is close to +1, there is little with-in group variance and a large group mean difference and HLM is the appropriate analysis. When ICC is negative or close to 0, there is large with-in group variance, a small group mean difference, and HLM is not warranted. ICC was calculated as the intercept variance component (r_0)/(intercept variance component (r_0) + total variance component (e). ICC for aerobics AVO2 was 0.67 or 67% therefore HLM was appropriate. Deviance for aerobics AVO2 from the null model was -353.63 with 3 estimated parameters. Table 15 provides a summary of results for Aerobics AVO2 models. Since the data were nested, it was appropriate to use deviance to compare models. In order for model fit to improve, whether the deviance is positive or negative, the value moves closer to zero.

An unconditional growth model was run using deviance and the number of estimated parameters from the null model. The unconditional growth model included the dependent variable as well as time at level 1. VO_2 (L/min) increased by 0.04±0.01 per year. Deviance in the unconditional growth model was -443.84 with 6 estimated parameters. Slope variance (0.002±0.05) was significant ($p<0.001$). However, since the addition of time at level 1 resulted in a deviance farther away from 0 compared to the null model, time did not improve model fit. Further analysis with a model that included the covariates CA, gender, and weight could not be run. There was a non-linear relationship associated with VO_2 L/min with the addition of the covariates in the model; therefore the HLM software could only run the analysis with errors. Figure 12 shows the small change in VO2 over time for aerobics. Figure 13 shows average VO_2 (L/min) by age for years 1 for aerobics.

Figure 12: Change in VO_2 over time for aerobics.

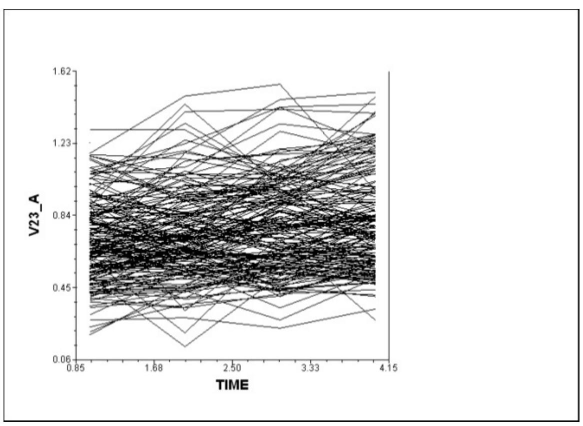


Figure 13: Average VO_2 (L/min) for year 1 by age for aerobics.

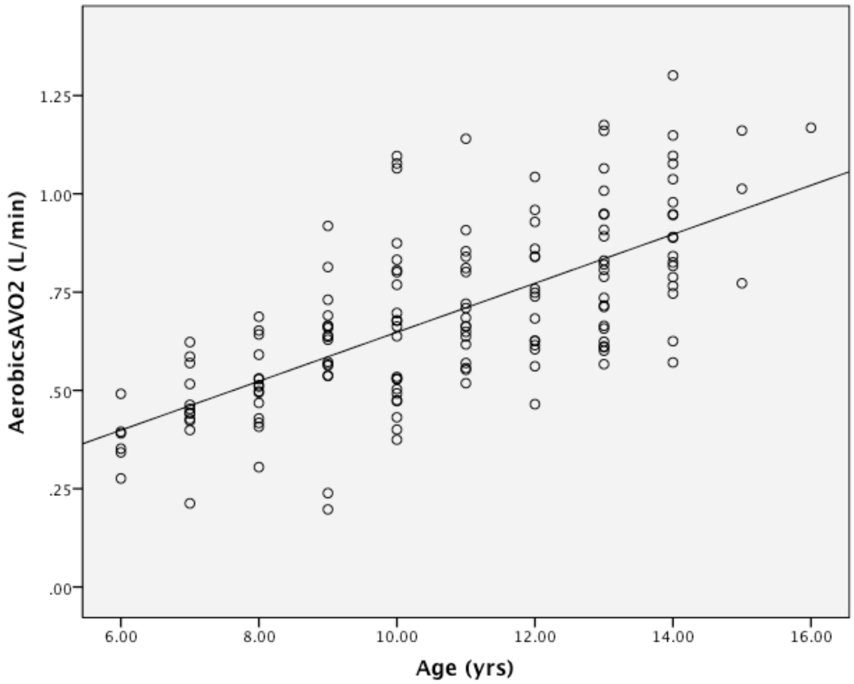


Table 15: Aerobics Absolute VO_2 (L/min) in youth over time.

Model	Null Model	Unconditional Growth Model
Variables		
Fixed effect	Estimates	Estimates
Constant (π_0)	0.74±0.02	0.65±0.02
Time (π_1)		0.04±0.01
Random effects	Level-1	Level-1
Constant (e)	0.02±0.14	0.01±0.11
	Level-2	Level-2
Intercept (r_0)	0.04±0.20	0.04±0.21
Slope (r_1)		0.002±0.05
Deviance	-353.63	-443.84
Change in deviance		90.21#
Estimated parameters	3	6

Fixed effects: coefficients ± Standard Deviation (S.D.) (VO_2, L/min)
Random effects: coefficients ± S.D. (VO_2, L/min)
^p<0.05 if 2 x S.D. for predictor variables of slope
#Slope remained significant in the final model (p<0.05)
*p<0.05 for change in deviance from previous model

Basketball: Absolute VO_2 (AVO_2; L/min)

A null model was run for basketball, which included only the dependent variable, VO_2, expressed in absolute terms (L/min). The null model was created to determine deviance for model comparison and to calculate ICC. Deviance from the null model was 333.63 with 3 estimated parameters. Table 16 is a summary of the models for basketball AVO_2 (L/min). The ICC was calculated from the null model as 0.68 or 68%. Since the ICC was close to 1, HLM was appropriate for analysis. An unconditional growth model was then created. The unconditional growth model included the dependent variable, VO_2, and time at level 1. Using deviance and number of estimated parameters from the null model, the unconditional growth model indicated whether or not model fit improved with the addition of time. Deviance from the unconditional growth model was 280.00. Since deviance moved closer to zero, this indicated that model fit improved with the addition of time. Slope variance (0.007±0.08) was also significant ($p<0.001$) indicating that there was variance in slope among participants. From the unconditional growth model, absolute VO_2 increased by 0.05±0.01 L/min per year.

Each predictor variable was entered into the unconditional growth model at level 2 at both the intercept and slope level one at a time to determine which predictor variables were significant without covariates (CA, gender, and weight) in the model. BSA (-0.13±0.04), REE (0.02±0.006), maturity (-0.06±0.02), LL (-0.003±0.001), and VE (-0.003±0.001) were significant at the slope level in level 2 while BF (-0.002±0.002) was not. A model was then run which included the covariates at level 2 at the slope and intercept level. The model with covariates produced a deviance of 116.00 with 12 estimated parameters. Using deviance and number of estimated parameters from the model with the covariates; each significant predictor variable was then entered into the model with the covariates one at a time to determine which predictor variables remained significant. BSA (0.91±0.45; p=0.045) was the only significant predictor variable at the slope level of level 2 in the model with covariates. CA (-0.03±0.008) was also significant ($p<0.001$) at the slope level. However, slope variance remained significant ($p<0.001$) indicating the predictor variables did not explain all of the variance among individuals in slope. Thus, VO_2 (L/min) increased by 0.05 L/min per year. With each one-unit increase in BSA (m^2), VO2 increased by 0.91 L/min. For each one-unit increase in CA (years), VO_2 decreased by 0.03 L/min. Figure 14 shows average VO_2 (L/min) by age for years 1 for basketball.

Figure 14: Average VO_2 (L/min) for year 1 by age for basketball.

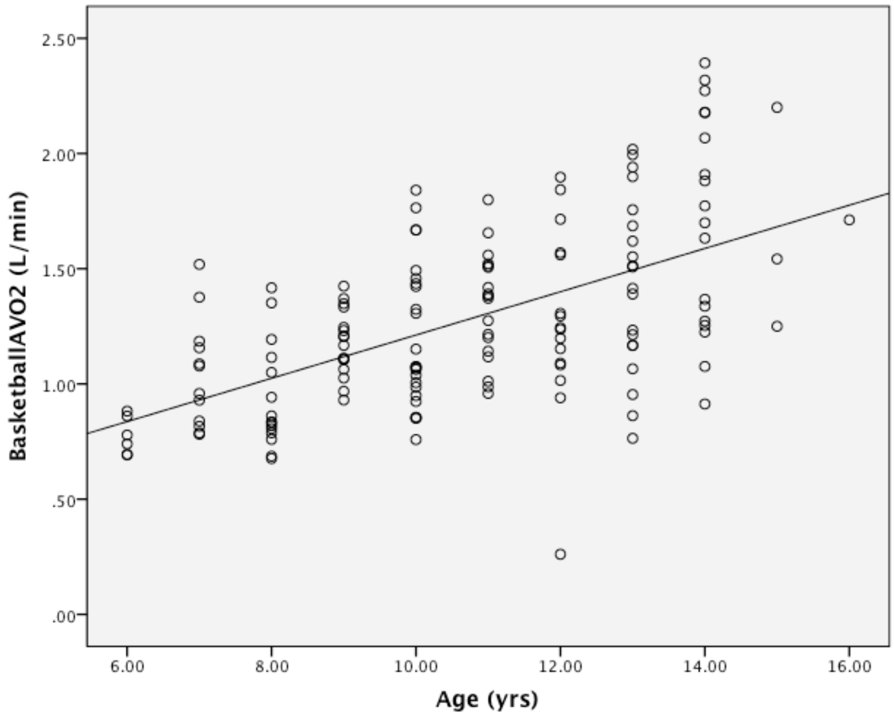


Table 16: Basketball Absolute VO_2 (L/min) in youth over time.

Model	Null Model	Unconditional Growth Model	Model with Covariates	Final Model
Variables				
Fixed effect	Estimates	Estimates	Estimates	Estimates
Constant (π_0)	1.40±0.03	1.28±0.04	1.07±0.14	-0.01±0.63
Gender			-0.25±0.05	-0.25±0.05
CA			0.06±0.02	0.04±0.02
Weight			0.01±0.003	-0.01±0.02
BSA				1.51±1.17
Time (π_1)		0.05±0.01	0.10±0.05	-0.44±0.25
Gender			-0.04±0.02	-0.03±0.02
CA			-0.02±0.005	-0.03±0.008^
Weight			0.0004±0.001	-0.02±0.008
BSA				0.91±0.45^
Random effects	Level-1	Level-1	Level-1	Level-1
Constant (e)	0.06±0.24	0.04±0.21	0.21±0.04	0.04±0.21
	Level-2	Level-2	Level-2	Level-2
Intercept (r_0)	0.13±0.36	0.14±0.37	0.15±0.02	0.02±0.14
Slope (r_1)		0.007±0.08	0.06±0.004	0.004±0.06#
Deviance	333.63	280.00	116.00	98.56
Change in deviance		53.64*	217.64*	17.44*
Estimated parameters	3	6	12	14

Fixed effects: coefficients ± Standard Deviation (S.D.) (VO_2, L/min)
Random effects: coefficients ± S.D. (VO_2, L/min)
^p<0.05 if 2 x S.D. for predictor variables of slope
#Slope remained significant in the final model (p<0.05)
*p<0.05 for change in deviance from previous model

Laundry: Absolute VO_2 (AVO_2; L/min)

The null model, which included only the dependent variable VO_2, was run to determine deviance for model comparison and to calculate ICC. The null model for laundry produced a deviance of -1124.17 with 3 estimated parameters. ICC was calculated as 0.53 or 53%. Since ICC was not close to 0, HLM analysis was appropriate. Using deviance and estimated parameters from the null model, an unconditional growth model, which included the dependent variable and time at level 1, produced a deviance of -1138.13 with 6 estimated parameters. In order for model fit to improve, deviance should move closer to 0. In this case, from the null model to the unconditional growth model, deviance moved farther away from zero indicating the addition of time in the unconditional growth model did not improve model fit. In the unconditional growth model, VO_2 (L/min) was found to increase by 0.008±0.003 L/min per year. Slope variance was significant ($p<0.05$) indicating there was some variance in slope among participants. To ensure model fit did not improve with the addition of covariates at the slope and intercept level of level 2, a model with the covariates CA, gender, and weight at level 2 was run. In the model with the covariates at level 2, deviance was -1231.20. Deviance continued to move farther away from zero in the model with covariates indicating model fit did not improve. Slope variance was also no longer significant ($p=0.05$) while none of the covariates in the model were significant. Thus, VO_2 (L/min) for laundry only increased by 0.008 L/min per year. While there was a difference in slope among participants, once the covariates were added to the model, slope variance was no longer significant meaning there was no variation among participants left to explain with predictor variables. Table 17 is a summary of all models for laundry expressed as absolute VO_2 (L/min). Figure 15 shows average VO_2 (L/min) by age for years 1 for laundry.

Figure 15: Average VO_2 (L/min) for year 1 by age for laundry.

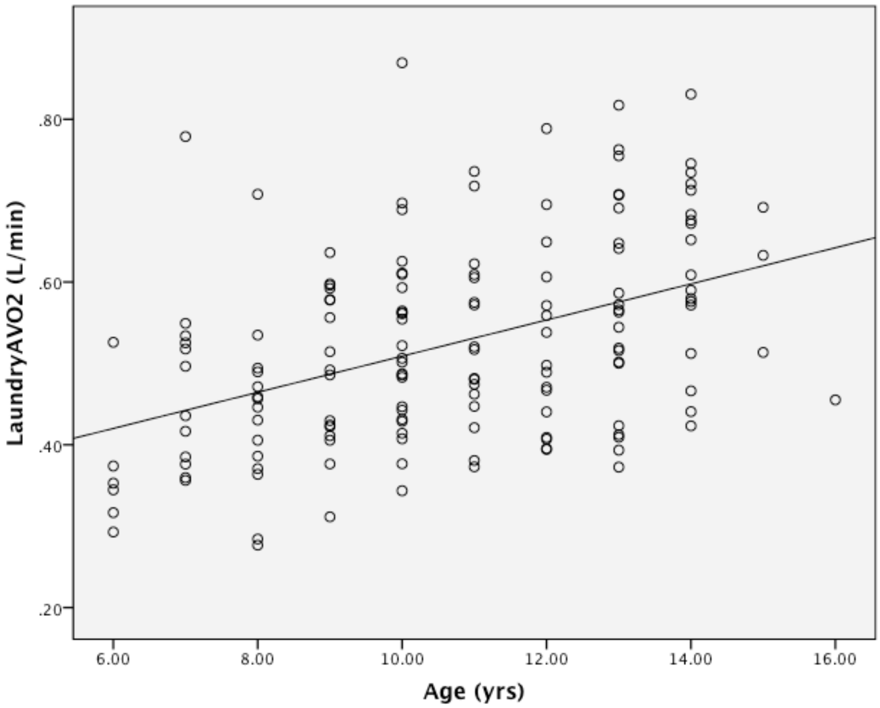


Table 17: Laundry Absolute VO_2 (L/min) in youth over time.

Model	Null Model	Unconditional Growth Model	Model with Covariates
Variables			
Fixed effect	Estimates	Estimates	Estimates
Constant (π_0)	0.54±0.008	0.52±0.01	0.35±0.05
Gender			-0.06±0.02
CA			0.001±0.007
Weight			0.006±0.001
Time (π_1)		0.008±0.003	0.05±0.02
Gender			-0.004±0.006
CA			-0.002±0.002
Weight			-0.0005±0.0004
Random effects	Level-1	Level-1	Level-1
Constant (e)	0.006±0.08	0.005±0.07	0.07±0.005
	Level-2	Level-2	Level-2
Intercept (r_0)	0.10±0.008	0.01±0.11	0.07±0.005
Slope (r_1)		0.0003±0.02	0.0002±0.01
Deviance	-1124.17	-1138.13	-1231.20
Change in deviance		13.95*	93.08*
Estimated parameters	3	6	12

Fixed effects: coefficients ± Standard Deviation (S.D.) (VO_2, L/min)
Random effects: coefficients ± S.D. (VO_2, L/min)
^p<0.05 if 2 x S.D. for predictor variables of slope
#Slope remained significant in the final model (p<0.05)
*p<0.05 for change in deviance from previous model

Sweeping: Absolute VO_2 (AVO_2; L/min)

The null model, which included only the dependent variables VO_2 (L/min) for sweeping, was run to determine deviance and ICC. The null model for sweeping produced a deviance of -904.3 with 3 estimated parameters. ICC was calculated as 0.54 or 54% indicating HLM the appropriate statistical test. Using deviance from the null model, an unconditional growth model was created. An unconditional growth model included the dependent variable and time at level 1. Using this deviance and number of estimated parameters from the null model, the unconditional growth model produced a deviance of -928.41 with 6 estimated parameters. In order for model fit to improve with the addition of time to the model, deviance should move closer to zero. With the unconditional growth model, deviance moved farther away from zero indicating the addition of time did not improve model fit. From the unconditional growth model, VO_2 (L/min) increased by 0.01±0.004 per year. Slope variance was significant ($p<0.001$) indicating there was variation in slope among participants. To ensure model fit did not improve with the addition of covariates to the slope and intercept level of level 2, a model that included CA, gender, and weight at level 2 was run. Deviance in the model with the covariates was -1016.49 and continued to move farther away from zero. Slope variance remained significant ($p<0.001$) and gender was significant in the model with covariates (-0.02±0.007). Thus, there was some variance in slope among participants in sweeping VO_2 (L/min) over four years. Gender (0=males, 1=females) explained some of this variance with being female decreasing VO2 by -0.02 L/min when controlling for CA and weight. However, since model fit did not improve with the addition of time and covariates, further analysis was not appropriate. Table 18 is a summary of all models for sweeping expressed as absolute VO2. Figure 16 shows average VO_2 (L/min) by age for years 1 for sweeping.

Figure 16: Average VO_2 (L/min) for year 1 by age for sweeping.

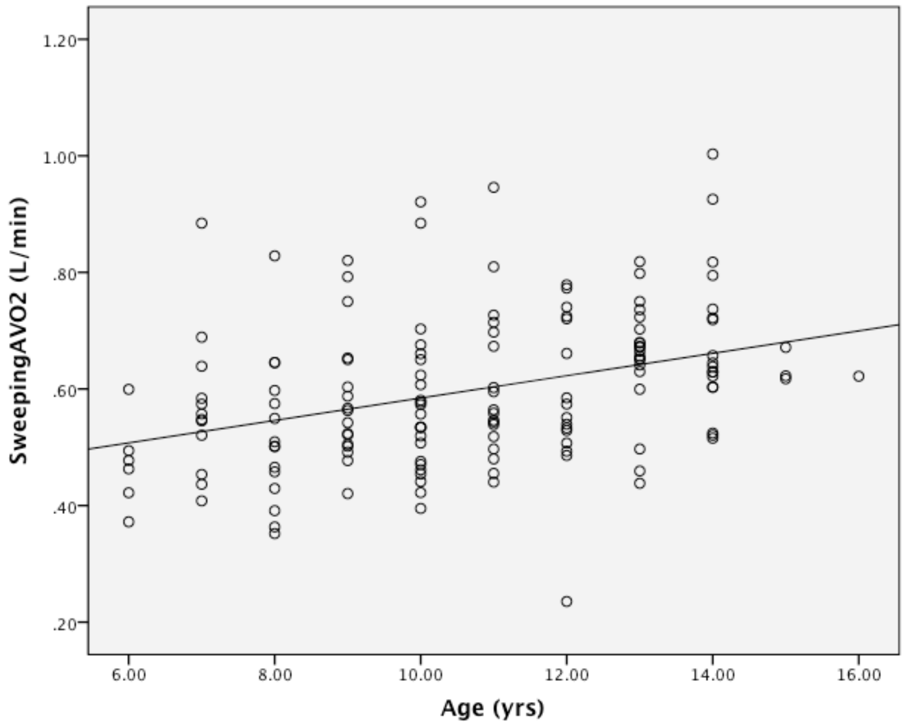


Table 18: Sweeping Absolute VO_2 (L/min) in youth over time.

Model	Null Model	Unconditional Growth Model	Model with Covariates
Variables			
Fixed effect	Estimates	Estimates	Estimates
Constant (π_0)	0.63±0.009	0.60±0.01	0.40±0.06
Gender			-0.02±0.02
CA			0.0007±0.007
Weight			0.006±0.001
Time (π_1)		0.01±0.004	0.08±0.02
Gender			-0.02±0.007^
CA			-0.003±0.002
Weight			-0.0001±0.0004
Random effects	Level-1	Level-1	Level-1
Constant (e)	0.09±0.009	0.08±0.007	0.08±0.007
	Level-2	Level-2	Level-2
Intercept (r_0)	0.10±0.01	0.01±0.11	0.008±0.09
Slope (r_1)		0.0008±0.03	0.0006±0.02
Deviance	-904.3	-928.41	-1016.49
Change in deviance		24.15*	88.07*
Estimated parameters	3	6	12

Fixed effects: coefficients ± Standard Deviation (S.D.) (VO_2, L/min)
Random effects: coefficients ± S.D. (VO_2, L/min)
^p<0.05 if 2 x S.D. for predictor variables of slope
#Slope remained significant in the final model (p<0.05)
*p<0.05 for change in deviance from previous model

Aerobics: Relative VO_2 (RVO_2; ml/kg/min)

A null model, which included only the dependent variable VO_2 (ml/kg/min), was run for aerobics. The null model was run to determine deviance for model fit and to calculate ICC. The null model produced a deviance of 3274.45 and 3 estimated parameters. The ICC was calculated from the null model to be 0.48 or 48%. Since ICC was not close to zero, HLM was the appropriate statistical analysis. An unconditional growth model was then run using deviance and number of estimated parameters from the null model. The unconditional growth model included the dependent variable and time at level 1. It was run to determine if model fit improved with the addition of time to the model and to determine if there was a difference in slope variance among participants. From the unconditional growth model, VO_2 decreased by 0.74±0.12 ml/kg/min per year. The unconditional growth model produced a deviance of 3215.56 with 6 estimated parameters and slope variance (0.73±0.86) was significant ($p<0.001$). Since model fit improved from the null model to the unconditional growth model (indicated by deviance moving closer to zero) and slope variance was significant, future analysis with predictor variables was appropriate.

Each predictor variable was then entered independently into the unconditional growth model at level 2 at the slope and intercept level. Predictor variables included BSA, REE, maturity, LL, BF, and VE. VE (-0.06±0.02) was the only significant predictor variable at the slope level at level 2 ($p<0.05$). BSA (0.80±0.43), REE (-0.13±0.08), maturity (-0.03±0.23), LL (0.007±0.01), and BF (0.03±0.02) were not significant at the slope level of level 2 ($p>0.05$). A model, which included only the covariates at level 2 at both the slope and intercept level, was then run. The covariates were CA and gender. Deviance from the model with covariates was 3199.99 with 10 estimated parameters. VE, the only significant predictor variable, was then entered into the model with the covariates at the slope and intercept level of level 2. VE (-0.12±0.03) remained significant and was included in the final model of best fit. In the final model, VE and CA were significant at slope level in level 2. However, slope variance remained significant ($p<0.05$). Thus, VO_2 decreased by 0.74 ml/kg/min per year. With each one unit increase in VE (L/min), VO_2 decreased by 0.12 ml/kg/min. With each one unit increase in CA (years), VO_2 increased by 0.23 ml/kg/min. Table 19 summarizes the results from the models for aerobics RVO2. Figure 17 shows average VO_2 (ml/kg/min) by age for years 1 for aerobics.

Figure 17: Average VO_2 (ml/kg/min) for year 1 by age for aerobics.

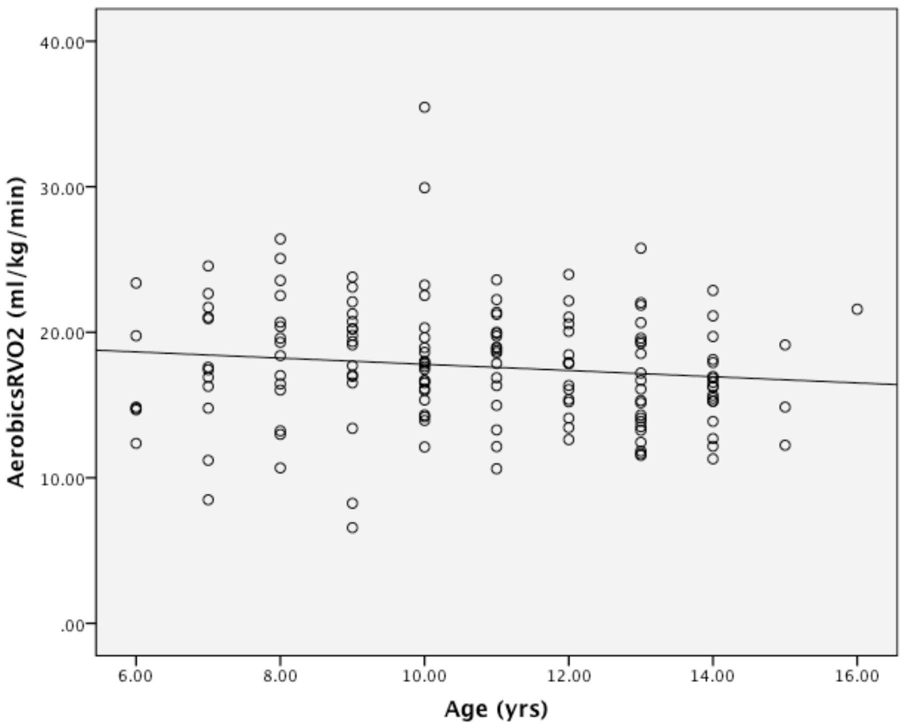


Table 19: Aerobics Relative VO_2 (ml/kg/min) in youth over time.

Model	Null Model	Unconditional Growth Model	Model with covariates	Final model
Variables				
Fixed effects	Estimates	Estimates	Estimates	Estimates
Constant (π_0)	16.44±0.26	18.28±0.41	19.94±1.25	10.17±2.37
Gender			-1.09±0.82	-1.28±0.75
CA			-0.29±0.16	-0.98±0.24
VE				0.45±0.12
Time (π_1)		-0.74±0.12	-0.41±0.37	1.69±0.54
Gender			-0.22±0.23	-0.17±0.22
CA			0.04±0.04	0.23±0.06^
VE				-0.12±0.27^
Random effects	Level-1	Level-1	Level-1	Level-1
Constant (e)	9.01±3.00	6.89±2.62	6.89±2.62	6.89±2.62
	Level-2	Level-2	Level-2	Level-2
Intercept (r_0)	8.25±2.87	15.57±3.94	14.72±3.84	11.08±3.33
Slope (r_1)		0.73±0.86	0.71±0.84	0.45±0.68#
Deviance	3274.45	3215.56	3199.90	3174.94
Change in deviance		58.89*	15.66*	25.00*
Estimated parameters	3	6	10	12

Fixed effects: coefficients ± Standard Deviation (S.D.) (VO_2, ml/kg/min)
Random effects: coefficients ± S.D. (VO_2, ml/kg/min)
^p<0.05 if 2 x S.D. for predictor variables of slope
#Slope remained significant in the final model (p<0.05)
*p<0.05 for change in deviance from previous model

Basketball: Relative VO_2 (RVO_2; ml/kg/min)

The null model, which included only the dependent variable VO2 ml/kg/min, was run for basketball. The null model was created to determine deviance and to calculate ICC. For relative VO2 (ml/kg/min) for basketball, the null model produced a deviance of 3984.83 with 3 estimated parameters. ICC was calculated as 0.58 or 58%. An unconditional growth model was then run, which included the dependent variable and time at level 1. The unconditional growth model was run to determine if there was variation in slope among participants and if model fit improved with the addition of time at level 1. The unconditional growth model produced a deviance of 3883.43 with 6 estimated parameters and slope variance (2.37±1.54) was significant ($p<0.001$). It was appropriate to add predictor variables to the model since model fit improved with time at level 1 and there was a difference in slope variance among participants. In the unconditional growth model, VO2 (ml/kg/min) was found to decrease by 1.80±0.21 each year.

Each predictor variable was then entered into the unconditional growth model independently at the slope and intercept level of level 2 to determine significant predictor variables. VE (-0.06±0.02) was the only significant predictor variable at the slope level in level 2 ($p<0.05$). BSA (0.30±0.80), REE (-0.03±0.14), LL (0.02±0.03), maturity (0.10±0.41) and BF (0.02±0.03) were not significant ($p>0.05$). Covariates CA and gender were then entered into a model at the slope and intercept level in level 2. Since VE was the only significant predictor variable independently, it was the only predictor variable entered into the model that included the covariates CA and gender. VE (-0.05±0.03) remained significant and was therefore included in the final model. Thus, VO2 decreased by 1.80 ml/kg/min per year. VE was the only significant predictor variable at the slope level. With every one-unit increase in VE (L/min), VO2 decreased by 0.05 ml/kg/min. However, slope variance remained significant ($p<0.001$) meaning that the predictor variables included in the final model could not explain all of the variance in slope among participants. Table 20 provides a summary of model for relative VO2 (ml/kg/min) for basketball. Figure 18 shows average VO_2 (ml/kg/min) by age for years 1 for basketball.

Figure 18: Average VO_2 (ml/kg/min) for year 1 by age for basketball.

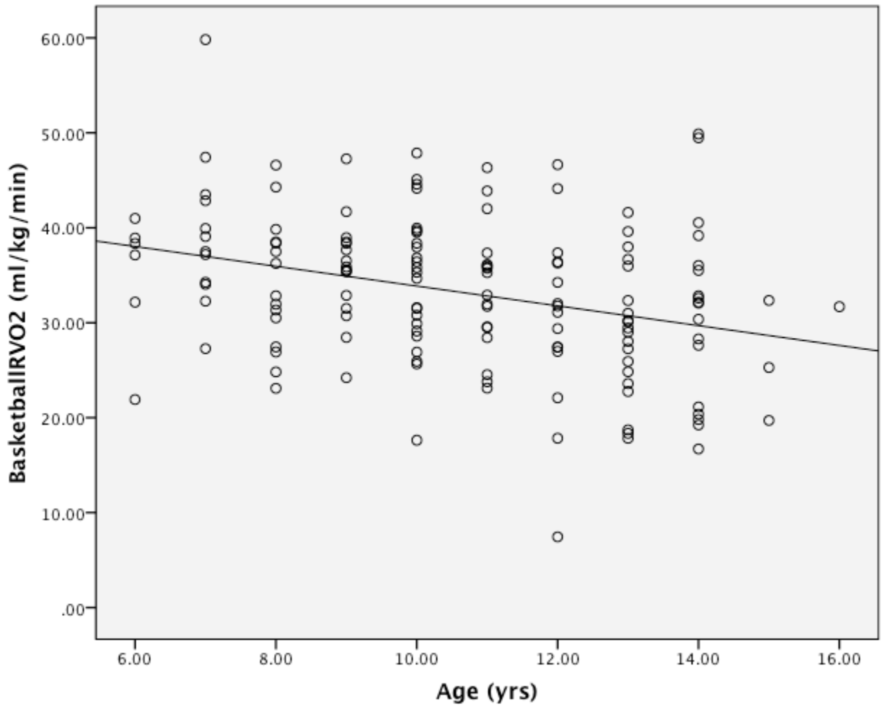


Table 20: Basketball Relative VO_2 (ml/kg/min) in youth over time.

Model	Null Model	Unconditional Growth Model	Model with covariates	Final model
Variables				
Fixed effects	Estimates	Estimates	Estimates	Estimates
Constant (π_0)	31.55±0.56	36.04±0.76	48.09±2.11	28.09±2.69
Gender			-7.98±1.31	-5.79±1.15
CA			-0.80±0.28	-1.46±0.32
VE				0.32±0.08
Time (π_1)		-1.80±0.21	-2.62±0.65	-0.05±1.12
Gender			0.55±0.41	0.18±0.38
CA			-0.14±0.08	-0.03±0.11
VE				-0.05±0.03^
Random effects	Level-1	Level-1	Level-1	Level-1
Constant (e)	29.43±5.42	20.10±4.50	20.10±4.48	20.10±4.48
	Level-2	Level-2	Level-2	Level-2
Intercept (r_0)	40.16±6.34	54.90±7.41	34.37±5.86	27.74±5.527
Slope (r_1)		2.37±1.54	2.18±1.48	2.00±1.41#
Deviance	3984.83	3883.43	3798.45	3780.48
Change in deviance		101.40*	84.98*	102.95*
Estimated parameters	3	6	10	12

Fixed effects: coefficients ± Standard Deviation (S.D.) (VO_2, ml/kg/min)
Random effects: coefficients ± S.D. (VO_2, ml/kg/min)
^$p<0.05$ if 2 x S.D. for predictor variables of slope
#Slope remained significant in the final model ($p<0.05$)
*$p<0.05$ for change in deviance from previous model

Laundry: Relative VO_2 (RVO_2; ml/kg/min)

The null model for relative VO_2 (ml/kg/min) for laundry, which included the dependent variables, was created to determine deviance for model comparison and to calculate ICC. The null model produced a deviance of 3068.44 with 3 estimated parameters. The ICC was calculated as 0.54 or 54%. Since ICC was not close to zero, HLM was the appropriate statistical analysis. An unconditional growth model was then created. The unconditional growth model included the dependent variable, VO2, and time at level 1. Using deviance from the null model, the unconditional growth model produced a deviance of 2861.14 with 6 estimated parameters and slope variance was significant ($p=0.026$). Since deviance moved closer to zero, this indicated that model fit improved with the addition of time. It was also appropriate to add predictor variables to the model since slope variance was significant, meaning there was variation in slope among participants. From the unconditional growth model, VO_2 (ml/kg/min) decreased by 1.05±0.08 per year.

Each predictor variable was entered into the unconditional growth model independently at the slope and intercept level of level 2. BSA (0.82±0.28), REE (-0.21±0.06), LL (0.03±0.01) and VE (-0.11±0.02) were all significant at the slope level in level 2 while maturity (0.22±0.15) and BF (0.02±0.009) were not. CA and gender were then entered into a model at the slope and intercept level of level 2. Each predictor variable that was found significant was then entered into the model independently with the covariates. BSA (0.72±0.35), REE (-0.20±0.06), LL (0.02±0.01), and VE (-0.15±0.03) were all significant at the slope level ($p<0.05$). BSA, REE, LL, and VE were included in the final model but only BSA, LL, and VE remained significant ($p<0.05$). For every one-unit increase in BSA (m^2) and LL (cm), VO2 increased by 2.50 ml/kg/min and 0.03 ml/kg/min, respectively. For every one-unit increase in VE (L/min), VO2 decreased by 0.25 ml/kg/min. CA was also significant indicating that for every one-unit increase in CA (years), VO2 decreased by 0.12 ml/kg/min. Slope variance was no longer significant ($p>0.500$) in the final model, meaning the predictor variables, BSA, LL, VE and CA, explained all of the variance in slope among participants. Table 21 provides a summary of model for relative VO2 (ml/kg/min) for laundry. Figure 19 shows average VO_2 (ml/kg/min) by age for years 1 for laundry.

Figure 19: Average VO_2 (ml/kg/min) for year 1 by age for laundry.

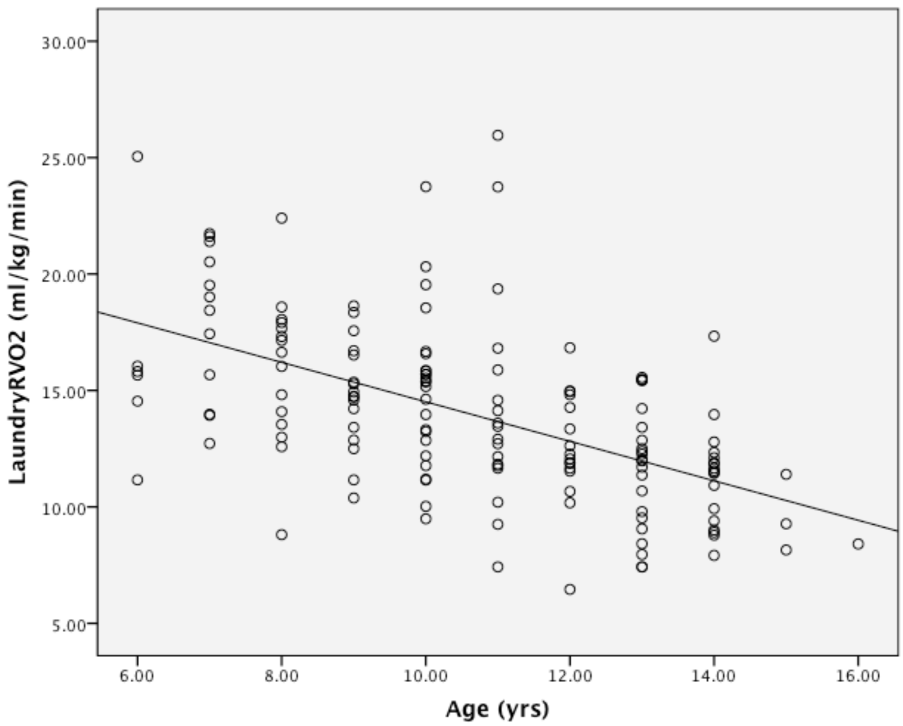


Table 21: Laundry Relative VO_2 (ml/kg/min) in youth over time.

Model	Null Model	Unconditional Growth Model	Model with covariates	Final model
Variables				
Fixed effects	Estimates	Estimates	Estimates	Estimates
Constant (π_0)	12.29±0.23	14.91±0.35	17.47±0.88	26.95±2.77
Gender			-1.69±0.57	0.08±0.37
CA			-0.97±0.12	0.30±0.13
BSA				-13.00±1.27
LL				0.16±0.03
VE				1.00±0.09
REE				0.28±0.18
Time (π_1)		-1.05±0.08	-1.32±0.23	-2.64±0.87
Gender			0.18±0.15	-0.16±0.13
CA			0.07±0.03	-0.12±0.04^
BSA				2.50±0.50^
LL				0.03±0.01^
VE				-0.25±0.03^
REE				-0.0007±0.06
Random effects	Level-1	Level-1	Level-1	Level-1
Constant (e)	5.69±2.39	3.57±1.89	3.54±1.88	3.23±1.80
	Level-2	Level-2	Level-2	Level-2
Intercept (r_0)	6.74±2.60	13.71±3.70	7.27±2.70	1.11±1.05
Slope (r_1)		0.17±0.42	0.15±0.38	0.002±0.05
Deviance	3068.44	2861.14	2750.36	2586.84
Change in deviance		207.29*	110.78*	163.51*
Estimated parameters	3	6	10	16

Fixed effects: coefficients ± Standard Deviation (S.D.) (VO_2, ml/kg/min)
Random effects: coefficients ± S.D. (VO_2, ml/kg/min)
^p<0.05 if 2 x S.D. for predictor variables of slope
#Slope remained significant in the final model (p<0.05)
*p<0.05 for change in deviance from previous model

Sweeping: Relative VO_2 (RVO_2; ml/kg/min)

The null model, which included only the dependent variable VO2 (ml/kg/min) for sweeping, was run. The null model was created to determine deviance for model comparison and to calculate ICC. The null model produced a deviance of 3111.16 with 3 estimated parameters. ICC was calculated as 0.57 or 57%, which indicated that HLM was the appropriate statistical analysis since ICC was not close to zero. An unconditional growth model was then run, which included the dependent variable and time at level 1. The unconditional growth model produced a deviance of 2895.77 with 6 estimated parameters. Since deviance moved closer to zero, this indicated that model fit improved with the addition of time. Slope variance was significant ($p<0.001$), indicating there was variance in slope among participants and it was appropriate to add predictor variables to the model. From the unconditional growth model, VO2 (ml/kg/min) decreased by 1.16 ml/kg/min per year.

Each predictor variable was then entered into the model independently at level 2 at both the slope and intercept level. Maturity (0.43±0.18), BSA (1.32±0.30), REE (-0.23±0.06), LL (0.02±0.01), and VE (-0.09±0.02) were significant at the slope level in level 2 ($p<0.05$). BF (0.02±0.01) was not significant. CA and gender were then added to the model as covariates at the slope and intercept level in level 2. Predictor variables that were found significant (maturity, BSA, REE, LL, and VE) were then added to the model with the covariates at the slope and intercept level of level 2 one at a time. BSA (1.43±0.47), REE (-0.22±0.07), and VE (-0.12±0.02) remained significant at the slope level in the model with the covariates ($p<0.05$). Maturity (0.30±0.25) was no longer significant. BSA, REE, and VE were included in the final model but only BSA and VE remained significant as did CA and gender ($p<0.05$). Thus, for every one-unit increase in BSA (m^2), VO2 increased by 2.78 ml/kg/min. For every one-unit increase in CA, gender, and VE, VO2 decreased by 0.09, 0.33, and 0.17 ml/kg/min, respectively. In the final model, slope variance was no longer significant ($p=0.196$), meaning the predictor variables explained all of the variance in slope among participants. Table 22 provides a summary of model for relative VO2 (ml/kg/min) for sweeping. Table 23 is a summary of all final HLM models. Figure 20 shows average VO_2 (ml/kg/min) by age for years 1 for sweeping.

Figure 20: Average VO_2 (ml/kg/min) for year 1 by age for sweeping.

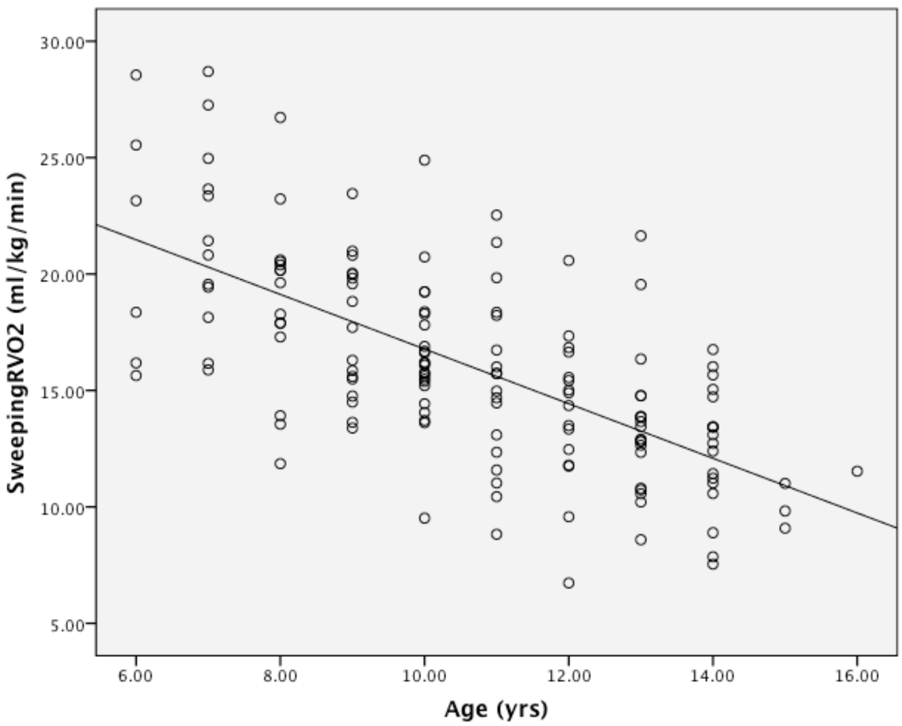


Table 22: Sweeping Relative VO_2 (ml/kg/min) in youth over time.

Model	Null Model	Unconditional Growth Model	Model with covariates	Final model
Variables				
Fixed effects	Estimates	Estimates	Estimates	Estimates
Constant (π_0)	14.41±0.27	17.31±0.41	18.61±1.03	21.12±2.47
Gender			-0.86±0.64	0.18±0.43
CA			-1.30±0.13	-0.08±0.13
BSA				-14.29±1.37
VE				0.68±0.07
REE				0.58±0.20
Time (π_1)		-1.16±0.09	-0.95±0.28	-0.29±0.87
Gender			-0.14±0.18	-0.33±0.16^
CA			0.12±0.04	-0.09±0.04^
BSA				2.77±0.48^
VE				-0.17±0.02^
REE				-0.06±0.07
Random effects	Level-1	Level-1	Level-1	Level-1
Constant (e)	6.81±2.61	3.61±1.90	3.61±1.90	3.61±1.90
	Level-2	Level-2	Level-2	Level-2
Intercept (r_0)	9.19±3.03	20.13±4.49	9.83±3.14	1.03±1.02
Slope (r_1)		0.57±0.76	0.49±0.70	0.09±0.30
Deviance	3111.16	2895.77	2756.94	2605.94
Change in deviance		215.39*	138.83*	151.0*
Estimated parameters	3	6	10	16

Fixed effects: coefficients ± Standard Deviation (S.D.) (VO_2, ml/kg/min)
Random effects: coefficients ± S.D. (VO_2, ml/kg/min)
$p<0.05$ if 2 x SD
*$p<0.05$ for change in deviance from previous model

Table 23: Summary of all HLM models for lifestyle activities.

Model	Slope (change in VO_2 over time)	Significant Predictor Variables	Slope variance in final model
Aerobics (L/min)	+0.04	N/A	N/A
Basketball (L/min)	+0.05	BSA, CA	Significant
Laundry (L/min)	+0.008	N/A	N/A
Sweeping (L/min)	+0.01	N/A	N/A
Aerobics (ml/kg/min)	-0.74	VE, CA	Significant
Basketball (ml/kg/min)	-1.80	VE	Significant
Laundry (ml/kg/min)	-1.05	BSA, VE, LL, CA	Not significant
Sweeping (ml/kg/min)	-1.16	BSA, VE, CA, Gender	Not significant

Discussion

The purpose of this study was to examine change in energy expenditure (VO_2) expressed in absolute (L/min) and relative (ml/kg/min) terms during four lifestyle activities over four years in children and adolescents. These four physical activities were selected because they are activities youth participate in on a regular basis (laundry and sweeping) or are skill-based activities (aerobics and basketball). A secondary purpose was to examine the factors that influence (predict) this change in VO_2. It was hypothesized that VO_2 would decrease over four years and BSA would be a significant predictor of change in energy expenditure for all four physical activities. In this study, the relative models (ml/kg/min) provided a better model fit compared to the absolute models for all four lifestyle physical activities. While BSA was significant for laundry and sweeping, VE was the only significant predictor variable for all four physical activities.

Traditionally, change in energy expenditure (often referred to as economy) has been expressed in relative terms (ml/kg/min)[2, 3]. In this study, VO_2 was expressed in absolute (L/min) and relative (ml/kg/min) terms in two separate HLM models for each of the four physical activities. There has been considerable debate about how to best scale and express VO_2 [33]. VO_2 was expressed in absolute terms (L/min) with weight as a covariate to take ratio scaling into account. However, model fit did not improve with the addition of time and the change in VO_2 was small (0.002 to 0.05 L/min) per year, which did not allow for much variation in slope among participants. For aerobics and laundry, the small change in VO_2 resulted in non-linear models and the data did not fit the model. Therefore, in the current study, expressing VO_2 in absolute terms was not appropriate for examining change in energy expenditure.

Previous studies addressing change in economy (ml/kg/min) with chronological age in youth have focused primarily on walking and running and have found that walking and running VO_2 decreased with chronological age in youth[5, 23]. This has been shown in cross-sectional studies comparing children and adults[2, 3] and children and adolescents[6]. Previous longitudinal studies have further shown that with increasing age, walking and running economy decreases in children[23] and adolescents into adulthood[5]. Very limited information is available related to change in economy in physical activities other than walking or running. Rowland et al. compared cycling economy between boys and men and found no difference in between groups[63]. In contrast, Turley et al. found men and women are more economical when cycling at 40 and 60 watts compared to boys and girls[78]. It should be noted that due to body size, 40 and 60 watts could be difficult for a child but a light intensity for an adult. In order for differences in economy to be compared, absolute intensity (speed or watts) must be matched between groups. This can make it difficult to compare economy between child and adults in various physical activities because a moderate intensity on a cycle ergometer, for example, may be a light intensity for an adult. In the current study, change in energy expenditure for four lifestyle physical activities was compared. While participants were read a standardized script prior to each activity, intensity was not measured. Heart rate was compared for each activity across the four years. In all four activities, heart rate significantly decreased each year. While this may suggest intensity was not matched year-to-year, it could also be due to the change in heart rate during submaximal exercise with age in children. Similar to previous findings with walking and running expressed in weight relative terms, energy expenditure decreased over time during aerobics, shooting hoops (basketball), a laundry task, and sweeping by 0.74, 1.80, 1.05, and 1.16 ml/kg/min per year, respectively.

The only common predictor variable among the four physical activities in this study was VE. Allor et al. also found when girls and women were matched for weight and height, girls expended more energy and had a higher ventilation and respiratory rate during walking and running[4]. Maliszewski and Freedson found men have higher ventilation than boys, although not matched for size, when running at absolute (9.6kph) and relative (3.71 leg lengths per second) speeds[1]. It is difficult to compare actual values of VE across studies due to different physical activities and intensities. However, one would expect, as children grow, ventilation will increase during submaximal activity[79]. That was not the case in the current study. VE increased each year in aerobics but stayed relatively the same across all four years for basketball, laundry, and sweeping. Participants were instructed to complete the same task (read a script) for all four activities each year. However, there was no measure to ensure intensity of the activities was standardized like speed in walking or running. Participants may have adjusted their intensity to a comfortable level. Respiratory rate and tidal volume were also not measured in this study so it is unclear why VE did not increase over the four years for basketball, laundry, and sweeping. While VE was a significant predictor variable for all four physical activities similar to that found by Allor et al.[4], VE in this study did not increase with age, possibly indicating participants were not working at the same intensity each year.

BSA has been previously associated with differences in energy expenditure between children and adults. Rowland et al. found boys and girls expend more energy when running on a treadmill at an absolute intensity compared to adults when VO2 is expressed as ml/kg/min[2, 3]. However, when VO2 was expressed relative to body surface area (ml/m^2/min) the difference in energy expenditure between children and adults disappeared[2, 3]. This is in accordance with the Surface Law, which states that smaller animals, such as children, expend more energy to maintain body temperature[61]. In the current study, similar to previous literature, BSA was found to influence change in energy expenditure for laundry and sweeping. However, BSA did not influence change in energy expenditure for aerobics or basketball. It is unknown why there is a difference in findings among the four physical activities but it could be due to the self-selected intensity of each activity.

Leg length was significant for the laundry trial only. Typically, stride frequency is related to energy expenditure, not leg length[11]. However, for the laundry trial in this study, stride frequency was not measured. For the laundry trial, after folding 5 towels, participants had to walk 10 feet between 2 tables to collect 5 more towels, then walk 10 feet back to the first table. While folding the towels, participants were stationary. Leg length in this case is most likely related to the walking portion of the laundry trial, not the actual folding of the towels since participants were standing still.

Another factor thought to contribute to change in energy expenditure is maturation[14]. Individuals do not grow and develop at the same rate and instead vary in their timing and tempo[34]. Therefore, a measure of maturity should be included when examining change in energy expenditure in youth. Maturity status can be determined by a number of different methods including stages of sexual maturation developed by Tanner, skeletal age, or age at peak height velocity making comparison among studies difficult. In general, studies examining change in energy expenditure in children and adolescents group participants by age and ignore maturity status.

Of the studies that have examined the effects of maturation on energy expenditure, the results are equivocal. Segers et al examined running economy in boys who played soccer grouped by maturity status[32]. Maturity status was determined by skeletal age using the Tanner-Whitehouse method. No difference in running economy was found between early and late maturing boys[32]. However, this study had a small sample size consisting of six early and seven late maturers. In a longitudinal study, Welsman and Armstrong examined changes in submaximal VO_2 related to age, gender, and maturation[33]. Participants were measured annually from age 11 to 13. Maturity status was determined by pubic hair development using stages developed by Tanner. Maturity status was found to have no effect on submaximal VO_2. They instead found skinfold thickness and body mass to have the greatest influence on submaximal VO_2. This indicates that body mass moved during submaximal exercise impacts VO_2 not differences in maturity status among participants[33]. This is not surprising since there is no proposed mechanism for why maturity status assessed by stages developed by Tanner is related to differences in submaximal VO_2.

One study has found maturity status to influence change in energy expenditure during running. Spencer et al. used data from the Saskatchewan Growth and Development Study[14]. In this study, maturation was assed by estimated age at peak height velocity. The authors found that late maturing boys from 10-14 years old had better running economy compared to early maturing boys when matched for chronological age. At age 12 and 13, average maturing boys were found to be more economical than early maturers[14]. In the current study, maturation was determined by estimated APHV for each participant. Due to the small sample size for early and late maturers, participants were classified as pre-APHV and post-APHV. However, in contrast to findings by Spencer et al., maturation did not influence change in energy expenditure in the four physical activities in this study.

The current study's lack of participants in the early and late groups could explain the difference in findings compared to the study by Spencer.

For laundry and sweeping, in the final model, slope was not significant. This means that the predictor variables VE, CA, and BSA explain all of the difference in change in energy expenditure among participants. For aerobics and basketball, slope remained significant in the final model indicating that the predictor variables in this study could not explain all of the variance in slope among participants. Other factors are thought to influence energy expenditure and were unable to be included in analysis. Although RER is thought to be related to change in energy expenditure in children and adolescents, it was not included in the models. RER was calculated from VO2 and VCO2 from the Oxycon. However, compared to Douglas Bags, the Oxycon does not produce a valid measure of VCO2[77]. Thus, despite the fact that RER is thought to influence change in energy expenditure, it could not be included in analysis.

In the final models of best fit (VO_2 ml/kg/min), slope variance was still significant for both aerobics (0.45±0.68; $p<0.05$) and basketball (2.00±1.41; $p<0.05$), indicating that, the predictor factors entered into the aerobics and basketball models were unable to explain all of the variance among individuals in regards to slope. Other factors have been identified previously that are related to change in economy in walking and running. These factors were not included in the current study because they were not measured but could explain the remaining slope variance. The higher metabolic cost in the younger children compared to older children could be due to cocontraction of agonist and antagonist muscles[12].

We did control for stride-to-stride variation and temporal structure of gait, which are thought to develop at different times in children and could influence change in energy expenditure[55]. There was also a skill component to each of the four activities, especially basketball. In the current study, there was no measure of skill and the decrease in energy expenditure could be partly due to participants simply becoming more scheduled at the different activities. Skill associated with physical activities should be considered in future studies related to change in energy expenditure.

There were strengths associated with this study. This was a mixed longitudinal study, which included children and adolescents participating for four years. This study included lifestyle physical activities that until the current study have not been examined related to change in energy expenditure. Another strength of this study was including many predictor variables related to change in energy expenditure in the HLM models.

There were limitations related to this study. As previously mentioned, physical activity intensity was not well-standardized across the four years. Previous studies that have explained change in economy in running have had participants run at the same absolute intensity. In this study, we did not have participants sweep, shoot hoops, or fold towels at the exact same rate each year. Therefore, we cannot determine for certain that participants were working at the same intensity each year. Heart rate was measured and compared across the four years for each activity. This was done to examine exercise intensity over time for each physical activity. Heart rate significantly decreased over time for each physical activity. This is to be expected. As children age, submaximal heart rate decreases over time. This makes using heart rate as a marker of intensity difficult since heart rate should decrease over time.

In conclusion, expressing energy expenditure in absolute terms (L/min) was not appropriate for measuring change in energy expenditure and predictors of change when controlling for CA, weight, and gender. When energy expenditure was expressed in relative terms (ml/kg/min), VO2 decreased in all four lifestyle physical activities over the four years. VE was the only significant predictor for all four activities. Future research should focus on standardizing the lifestyle physical activities across all time points, including and examining VE as a predictor variable, and including other factors related to change in energy expenditure that could not be addressed in this study.

CHAPTER 5

SUMMARY AND FUTURE RECOMMENDATIONS

The purpose of this dissertation was to examine longitudinal changes in economy and energy expenditure in children and adolescents. To the author's knowledge, this is the first longitudinal study to include children and adolescents, males and females, and a variety of physical activities. Six physical activities (walking, running, aerobics, laundry, basketball, and sweeping) were examined, and energy expenditure was expressed in absolute terms (L/min) and relative terms (ml/kg/min) in two separate HLM models for each activity. The major findings were that economy/energy expenditure decreased over time for the six physical activities and that ventilation was the most common predictor of change in economy/energy expenditure.

Absolute VO_2 models

Traditionally, change in economy (energy expenditure) is expressed as VO_2 in relative terms (ml/kg/min)[1]. However, there has been recent debate in the literature over how to express VO_2. Creating HLM models for the six physical activities in absolute terms and including weight (kg) as a covariate is an approach similar to ratio scaling (modeling as ml/kg/min). However, results did not support this approach, because data from four of the six physical activities did not fit the model. Previous research shows VO_2 (ml/kg/min) decreases over time in children and adolescents[5, 23]. The absolute models (L/min) in the current study all showed an increase in VO_2 over time, which makes sense given that many of the participants were still growing, or simply gained weight, even if their height did not change. Results from the absolute models did not support the hypotheses for Aim 1 that VO_2 would decrease over time for the six physical activities. The increase in VO_2 (L/min) from year to year was small, creating very little variance in slope among individuals. For Aim 2, BSA was a significant predictor of slope, which supported the hypothesis. Results from this analysis should be used with caution since VO_2 increased over time. Since the data did not fit the models for the other physical activities, the hypotheses for Aim 2 were not supported. Table 24 provides an overall summary of the absolute models for the six physical activities. Based on the results of the current study, expressing VO_2 in absolute terms was not an appropriate way to examine change in economy and energy expenditure in children and adolescents.

Table 24: Overall summary of absolute VO_2 HLM models.

HLM models (L/min)	Change in VO_2 per year	Significant predictor variables	Slope variance in the final model
Walking	+0.04	N/A	N/A
Running	+0.13	Gender	Significant
Aerobics	+0.04	N/A	N/A
Basketball	+0.05	BSA, CA	Significant
Laundry	+0.008	N/A	N/A
Sweeping	+0.01	N/A	N/A

Relative VO_2 models

Previous studies examining economy during walking and running show VO_2 (ml/kg/min) decreases over time in children and adolescents[2, 3, 5, 23]. In the current study, similar to previous research, VO_2 decreased each year by 1.19 and 0.87

ml/kg/min for walking and running, respectively, in children and adolescents. These results support the hypotheses for Aim 1 (Hypotheses 1 and 2) that VO_2 (ml/kg/min) would decrease over time for walking and running. The current study examined change in energy expenditure over time in children and adolescents for aerobics, basketball, laundry, and sweeping. VO_2 (ml/kg/min) decreased over time in all four lifestyle physical activities. This supports Hypotheses 3-6 for Aim 1 that VO_2 would decrease over time for the four lifestyle activities. Similar to walking and running, lifestyle physical activities required less energy to complete the task as youth aged. Table 25 is an overall summary of the relative models for the six physical activities.

Table 25: Overall summary of relative VO_2 HLM models.

HLM models (ml/kg/min)	Change in VO_2 per year	Significant predictor variables	Slope variance in the final model
Walking	-1.19	VE, CA, BSA, LL	Significant
Running	-0.87	LL	Significant
Aerobics	-0.74	VE, CA	Significant
Basketball	-1.80	VE	Significant
Laundry	-1.05	BSA, VE, CA	Not Significant
Sweeping	-1.16	BSA, VE, CA	Not Significant

According to the literature, a number of factors are thought to contribute to the decrease in VO_2 (ml/kg/min) over time. These factors include age[2, 3], resting metabolic rate[7, 8], body size[1], gender[9], substrate utilization[10], biomechanics[11, 12], training[13], ventilation[2], and maturation[14]. Based on previous literature, factors for the current study were identified and included in the HLM models. Significant predictor variables for all six physical activities are found in Table 22.

The most common predictor variable was VE, which was significant in five of the six physical activities. This does not support hypotheses 1-6 for Aim 2. Results from the current study are similar to Allor et al.[4]. They found that when girls and women were matched for height and weight, girls had a higher VE and expended more energy than women during walking and running[4]. One would expect VE to increase over time as children grow. That was not always the case in the current study. VE increased over time for walking and aerobics, but not running, basketball, laundry, and sweeping. For basketball, laundry, and sweeping, this could be due lack of control of the workload each year, even though participants were read a standardized script. It is surprising that VE did not increase each year for running since speed was controlled. This could be due to participants self-selecting their pace during year 1. It could also be due to respiratory rate, since Allor et al. found respiratory rate was higher in the girls compared to women[4]. Unfortunately, respiratory rate was not analyzed in the current study. VE is not commonly recognized as a factor related to change in economy and energy expenditure. However, the current study suggests VE is an important, common factor among five different physical activities. Respiratory rate and tidal volume were not measured in the current study. Future studies should address components of VE to determine what specifically is influencing economy.

It has been well documented in the literature that economy improves with CA[5, 23]. Rowland et al. found men are more economical than boys during running[2].

Similar results were found for girls[3]. Ariens et al. found running economy improved with CA for boys and girls[5]. In the current study, while VO_2 improved over time in all six physical activities, CA was only a significant predictor variable for walking, aerobics, laundry, and sweeping. It is surprising, that in contrast to the literature, CA was not a predictor variable for running. However, previous studies do not include CA as a predictor variable. Instead, participants are either separated into groups based on age (e.g. adults and children) or followed over time, thus CA increases. This could explain the contrasting results for running in the current study compared to previous literature. When included as a predictor variable, CA explains some, but not all, of the differences in economy and energy expenditure in youth over time.

BSA was a significant predictor variable for walking, laundry, and sweeping. It was hypothesized that BSA would be a significant predictor variable for all six physical activities. Results for BSA support hypotheses 1, 3, and 5 but not 2 and 4 for Aim 2. BSA has been identified as a factor related to change in energy expenditure due to the Surface Law. The Surface Law states that oxygen consumption and heat production is higher in smaller animals[36]. Rowland et al. scaled VO2 relative to body surface area and found that there was no longer a difference in economy between girls and women during running, which supports the Surface Law[2]. In contrast, Allor et al. found that when girls and women were matched for height and weight, girls had a higher VO_2 for both walking (16.4±1.7 vs. 14.4±1.1 ml/kg/min) and running (38.1±3.7 vs. 33.9±2.4 ml/kg/min)[4]. Results from the current study for walking, laundry, and basketball support those of Allor et al. that BSA explains some, but not all, of the differences in economy and energy expenditure.

Previous studies have identified stride frequency, not leg length, as a factor related to economy. Unnithan and Eston found boys had a higher VO2 and stride frequency during running compared to men[11]. However, there was no difference in the oxygen cost per stride between the two groups. Stride frequency was included in the walking and running HLM models. However, leg length, not stride frequency, was significant. Results do not support hypotheses 1 and 2 for Aim 2. For running, leg length was the only significant predictor variable. Differences in results could be due to the self-selected pace for running and/or due to the fact that walking and participants walked overground versus on a treadmill. Previous research has primarily required participants to walk or run on a treadmill, which may propel their legs forward. Future research examining economy in walking and running should focus on both stride frequency and leg length as a factor related to change over time.

In two of the lifestyle physical activities, laundry and sweeping, slope was not significant in the final HLM model. This means that the predictor variables BSA, CA, and VE explained all the variance in slope among participants. For the other four physical activities, slope was still significant in the final model and could not be fully explained by the predictor variables available. There are other factors related to change in energy expenditure that could not be included in the HLM models in the current study. RER and RMR were both calculated in the current study. However, neither was used in the analyses due to lack of validity for assessing VCO_2 (when using the portable metabolic analyzer), which is included in RER, and multicollinearity of REE. The current study also did not include any biomechanical factors. Previous literature has identified several biomechanical factors related to economy. Biomechanical factors such as cocontraction of agonist and antagonist muscles[12], stride-to-stride variability[55], and optimal stride length[54] were not measured and therefore not included in analyses. Future research examining change in economy and energy expenditure should include these factors to explain at least some of the remaining slope variance in walking, running, aerobics, and basketball.

In summary, expressing VO_2 in absolute terms (L/min) was not appropriate for examining change in economy and energy expenditure over time in children and adolescents. When expressed in relative terms (ml/kg/min), VO2 decreased over time in all six physical activities. VE was the most common significant predictor of change in energy expenditure. CA, BSA, and LL were identified as significant predictors of slope. This dissertation added to the current literature by including activities beyond walking and running, examining predictor variable related to economy in one model, and by including participants over a wide age range. The following section addresses future directions for this line of research.

Recommendations for future research

Further research on change in economy in children and adolescents will provide valuable information related to the development of the Compendium of physical activities for youth and performance in a variety of sports (i.e. running performance).

The following studies outlined below are suggested for future research:

- The majority of literature related to economy has required participants to walk on a treadmill, not overground, as in the current study. Overgound is more practical as children and adolescents complete this task on a daily basis. Future research should compare economy in children and adolescents when walking overground and on a treadmill.
- Invite participants in the current study to participate in a 5 and 10-year follow-up to examine the change in economy/energy expenditure into young adulthood.
- Rank participants from most economical to least economical in the current study and determine if rank remains relatively stable over the four years of data collection.
- Include factors that have been identified related to economy in previous studies that were not able to be included in the current study such as: a true REE measure not pre-exercise, RER, and stride length.
- Include other physical activities that children and adolescents participate in on a regular basis and better standardize these activities by including a measure of intensity/work load.

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