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RUNNING ECONOMY AND PERCEIVED EXERTION IN ADOLESCENT GIRLS

By

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ABSTRACT

RUNNING ECONOMY AND PERCEIVED EXERTION IN ADOLESCENT GIRLS

By

Karin Allor Pfeiffer

This dissertation includes an introduction (Chapter 1), a review of literature (Chapter 2) and two papers. In the first paper (Chapter 3), the relationship between age and exercise economy in adolescent girls, ages 13-18, was examined. In the second paper (Chapter 4), the reliability and validity of two methods for determining rating of perceived exertion (RPE) in adolescent girls was examined. Chapter five includes discussion of the relationships between exercise economy, RPE, and physical activity. All data included the same group of adolescent girls.

Exercise economy generally improves as a function of age, but the relationship was not found in this dissertation. Heart rate was found to be the best predictor of oxygen consumption (VO_2) for three treadmill stages employed in the exercise protocol. Ventilation, body surface area, stride frequency, and aerobic capacity were other variables that helped predict VO_2 during exercise. Study participants were fitter than average girls their age. The treadmill speeds chosen may have impacted the results by causing inefficient running mechanics, thus masking any relationship that may have existed.

The Borg category RPE scale and the OMNI RPE scale were tested for reliability and validity. Results showed that the OMNI scale was both more reliable and valid than the Borg scale for this sample of adolescent girls.

Study results infer a potential relationship between exercise economy, RPE, and physical activity. Although the number of participants was not large enough to perform inferential statistics, economy correlated fairly well with number of days of the week on which girls exercised vigorously for 20 minutes or more. Running economy also correlated well with OMNI RPE during stage 3 of the treadmill test. More research is needed before any directionality or causality can be determined from these potential relationships.

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CHAPTER 1

INTRODUCTION

Physical activity, defined as any bodily movement produced by skeletal muscles that results in caloric expenditure[14], has been cited as an important variable affecting chronic disease in adults[76]. It has been found to have an inverse association with coronary heart disease incidence and morbidity and mortality of several chronic ailments[59]. Recent data suggest that incorporating physical activity into one's lifestyle may improve the person's cardiovascular disease risk factor profile, particularly if this behavior becomes habitual early in life[76]. Researchers have also found that physical activity declines during adolescence, especially in females [48]. Although there is only moderate evidence that physical activity tracks (i.e., remains stable) from childhood to adulthood [49], researchers generally agree that it is important for children to become and stay physically active [6]. The Surgeon General's Report on Physical Activity and Health indicates that children should participate in regular physical activity, and continue to do so throughout their lives[76]. Two important questions for researchers are 1) how to get children to be physically active and 2) how to get them to stay physically active throughout adolescence, so that they might improve their chronic disease risk factor profiles during adulthood.

Exercise economy, defined as the amount of energy required to perform work at a submaximal intensity, may be an important factor affecting physical activity behavior. Individuals with poor economy may have difficulty performing physical activities and thus, be less likely to perform them on a routine basis. Studies have found that children are less economical than adults during exercise [1, 69, 71, 78]. Possible factors cited include body size (including obesity), maturation, pulmonary and cardiac characteristics, resting energy expenditure, substrate utilization, running mechanics, and training [56, 66, 67]. Of these potential factors, body size has been commonly cited as a variable affecting running economy [69, 71]. However, the child study participants were always smaller than the adult participants, leaving it questionable whether body size was the only variable related to the poorer economy in children. In a recent study, we examined 13 year-old girls and 23 year-old women of similar heights and weights [1]. Despite being the same size, the girls were still less economical than the adults, although the difference in energy expenditure was less than found previously [65, 71]. Thus, the true nature of the relationship between economy and age in females remains unclear.

Exercise economy may affect ratings of perceived exertion (RPE). Perceived exertion is defined as the ability to detect and respond to sensations that arise as a result of physiological adaptations to exercise [57]. The most common way to assess RPE is use of the Borg category scale. The original Borg 15-point RPE scale was developed for use with adult males. Some researchers have found that adults and children differ in their ratings of perceived exertion at a given workload using this instrument [7]. There is also evidence suggesting that the scale is valid with children [22]. Recently, researchers have proposed a new instrument for measuring RPE in children, the OMNI Scale of Perceived Exertion [60]. It is not clear whether one scale may be more valid or reliable than the other for any given activity session. Further, it is not known how exercise economy may relate to either of these methods used for measuring perceived exertion in children.

This dissertation is divided into two studies with one comprehensive review of literature (Chapter 2). The first study (Chapter 3) examines determinants of, and differences in exercise economy in adolescent girls ages 13-18 years. The second study (Chapter 4) focuses on RPE during submaximal exercise conditions using the Borg and OMNI scales. Chapter five examines the relationships between economy, RPE and physical activity (estimated by participant recall).

Overall, this dissertation includes four research questions and hypotheses:

Research Question 1: Do walking and running economy improve as a function of age in adolescent girls, ages 13-18 matched for height and weight?

Hypothesis: As age increases, walking and running economy will improve

Statistical Analysis: A two-way ANOVA (age group and treadmill speed), with repeated measures across one factor (treadmill speed). Stepwise linear regression analysis to determine predictors of walking and running economy

Research Question 2: Does body mass index (BMI) affect walking and running economy in adolescent girls?

Hypothesis: There is no difference in walking and running economy between normal BMI and higher BMI girls

Statistical Analysis: ANOVA to determine differences between groups

Research Question 3: What is the reliability and validity of the two different methods for measuring children's RPE?

Hypothesis: The Borg and OMNI scales have similar reliability and validity

Statistical analysis: ANOVA to determine intraclass correlation for reliability and Pearson correlations to determine validity, using percent of heart rate maximum and percent of aerobic capacity as criterion measures

Research Question 4: Is there a relationship between exercise economy, RPE, and physical activity?

Hypothesis: Both economy and RPE will be related to physical activity

Analysis: Pearson correlations to determine potential relationships between economy, perceived exertion, and physical activity

CHAPTER 2

REVIEW OF LITERATURE

INTRODUCTION

Exercise economy is a potential determinant of physical activity in children. Researchers have not examined the relationship between economy and physical activity, and it is possible that there are some intervening variables that affect this potential relationship. For example, economy could possibly affect one's RPE, which also may be related to physical activity. The focus of this literature review will be to outline what is currently known about economy and RPE. At the present time, this author has not found any studies examining the relationship of economy or RPE to physical activity.

EXERCISE ECONOMY

Exercise economy can be defined as the volume of oxygen (VO_2) required to perform an activity at a given submaximal workload. During weight bearing activities such as walking and running, the VO_2 is typically indexed by body weight ($ml \cdot kg^{-1} \cdot min^{-1}$). It has been shown to be a factor affecting endurance performance, particularly when individuals with similar fitness levels are compared [35]. Several factors are thought to contribute to economy, including age, sex, body size, maturation, pulmonary parameters, cardiac function, resting energy expenditure, substrate utilization, running mechanics, and training status [56, 66]. Also, allometric scaling, reliability of submaximal exercise testing data (intra-individual variation), and treadmill habituation can affect economy and/or how economy is expressed. A discussion of each of the potential determinants follows.

Age and economy

Age has been shown to be a major factor affecting walking and running economy. Pate et al. [58] showed that economy declines with age in 20-60 yr-old adult runners. They measured economy in a stratified random sample of participants from the Carolina Runners Study (the strata were based on age, gender, and weekly running miles) and used multiple regression to determine predictors of economy (r^2 for full model was 0.58). Bailey and Pate [5] later reported that the relationship between age and economy is parabolic, with younger and older individuals having poorer economy compared to those of middle age. The researchers also found that body weight, in addition to age, was significantly associated with economy in adults [58]. Similarly, Freedson et al. [24] reported evidence that seemed to indicate differences in the relationship between economy and age during childhood and adulthood. Thus, it is important to consider that the nature of the relationship between age and economy may change over time.

Many who have investigated the relationship between age and economy have focused on child-adult differences. In all studies comparing children to adults, researchers have reported that children are less economical than adults, with differences ranging from 2-10 $ml \cdot kg^{-1} \cdot min^{-1}$ [1, 19, 69, 71, 78]. Studies involving walking economy have indicated that the economy difference between children and adults is greater in pre-pubescent children [19] than pubescent/post-pubescent children [1] (3-5 $ml \cdot kg^{-1} \cdot min^{-1}$ difference vs. 2 $ml \cdot kg^{-1} \cdot min^{-1}$ difference, respectively). Adult-child differences in economy appear to be greater during running. Unnithan found a difference ranging from 5-8 $ml \cdot kg^{-1} \cdot min^{-1}$ in boys age 10 (pre-pubescent) versus men age 20 years [78]. In another study including pre-pubescent boys, the authors reported a child-adult economy difference of 10 ml·kg^{-1}·min^{-1} [69]. When examining child-adult differences between premenarcheal girls and women, Rowland and Green [71] found a 5 ml·kg^{-1}·min^{-1} difference. Differences of 4 ml·kg^{-1}·min^{-1} were found between postmenarcheal girls and women in another study [1]. Although it appears that the child-adult differences in boys versus men may be higher than those in girls versus women, it is not clear how the combined effects of pubertal status, gender, and running speed may affect economy differences.

Other investigations of economy have focused on differences between children of various ages or between children and adolescents. Astrand [4] was the first to examine economy in children and adolescents. He found that younger participants used more O_2 per kg body weight (were less economical) than older participants and that there was an inverse, linear relationship between VO_2 and age.

In addition to Astrand, other researchers have found a linear relationship between age and VO_2 in children/adolescents. MacDougall et al. [42] found a linear relationship between age and VO_2 in a cross-sectional sample of children ages 7-16. As the participants' ages increased, the VO_2 decreased (economy improved), and differences in running economy were not more than 5 ml·kg^{-1}·min^{-1} [42] between the youngest and oldest children (ages 7-16). In a sample of children ages 6-12 and adolescents ages 13-19, Waters et al. [83] found a linear relationship when they plotted age versus VO_2 and determined a line of best fit using linear regression. Results showed a significant difference (3 ml·kg^{-1}·min^{-1}) in walking economy between the two groups, with the older children being more economical than the younger ones.

McCormack et al. [53] divided participants into three age groups, 6-8 years, 9-11 years, and 12-14 years. All study participants ran at 5.0 mph on a motorized treadmill. The authors found that running economy increased significantly with age across the three groups (no more than 5 $ml \cdot kg^{-1} \cdot min^{-1}$), but they also examined the results with respect to gender. On average, the oldest group of boys was more economical than the younger two groups, while the older two groups of girls were more economical than the youngest girls. A limitation of examining the differences between genders was small group sample size. Specifically, subject number ranged from 6-14 among the groups. Another limitation in these studies comparing both children and adolescents is lack of assessment of maturity status. It is unknown how maturation may have affected any of these results.

Some researchers contend that the relationship between age and economy may not be linear. Freedson et al. [24] reported a curvilinear relationship between speed and VO_2 in children. Although Freedson et al. did not examine the relationship between age and economy itself, their results suggested that age may affect economy differently during childhood versus adulthood due to the relationship between body size at various ages and speed.

All studies mentioned thus far included only cross-sectional data. The best method to determine the effect of age on economy is to perform longitudinal studies that would show change over time within individuals. Unfortunately, there are not adequate longitudinal data available to determine how an individual's economy changes throughout his or her lifespan. It is difficult to maintain a sizable study cohort for an extended period of time. The longitudinal studies that do exist will be discussed next.

In one longitudinal study, Ariens et al. examined adolescents at age 13 and followed them until age 27 [2]. The researchers did not collect data on participants every year, but they selected various time points (ages 13, 14, 15, 16, 21, 27). The authors claimed that the largest change in economy occurred at puberty (ages 13-16) [2]. However, they noted that the participants may not have been at steady state during exercise because the test stages were only two minutes. Four to five minutes is usually considered the minimal time needed to achieve a metabolic steady state [67]. Further, the authors did not note the pubertal status of the girls. If their sample included early maturers, then perhaps some other physiological aspect of maturation (e.g., maturation of the pulmonary system) aside from puberty itself may have affected change in economy in the 13-16 year-old age group.

Two research groups measured economy at the beginning and end of three and five year time periods, and could not account for changes that may have occurred in the interim [23, 35]. In both studies, researchers began testing economy when the participants were pre-pubescent. The first study lasted three years. Based on the children's ages it is likely that they were still pre-pubescent at the end of the investigation, although the authors did not account for this [23]. The researchers reported an economy difference of approximately 6 $ml \cdot kg^{-1} \cdot min^{-1}$ from beginning to end. The other study included participants who were most likely post-pubescent at the end of the study, according to their ages (mean age = 17 years) [35]. Economy differences ranged from 0.6-3.0 $ml \cdot kg^{-1} \cdot min^{-1}$ from the first test to the second test, which was 7 years later. However, the participants did not perform the same protocol at both time periods. Rather, they completed a protocol that the researchers thought would evoke the same relative exercise intensity at both ages. Thus, it is difficult to determine what economy changes truly occurred.

Researchers have also examined exercise economy at yearly intervals during longitudinal studies. Rowland et al. [64] studied participants every year over five years. All participants were pre-pubescent at the beginning of the study and were pubescent or post-pubescent (according to parents assessment of pubic hair development, voice change, or facial hair) at the end of the study. The economy difference cited was 4-5 $ml \cdot kg^{-1} \cdot min^{-1}$ overall, with the greatest changes occurring between years three and four of the study. In another study, Daniels et al. used a mixed-longitudinal design, and results indicated a general linear trend toward an increase in economy with age [16]. However, their results showed a deviance from the linear trend at puberty, and training status may have confounded the results.

Gender and economy

It is possible that gender plays a role in exercise economy. Many exercise economy studies have focused specifically on boys or men. There are few studies in which male versus female comparisons have been made in children, and the existing literature regarding economy differences between boys and girls is equivocal. Some studies suggest that girls display better economy than boys. In pre-pubescent children, Freedson et al. [24] found a gender difference in economy of 3-4 $ml \cdot kg^{-1} \cdot min^{-1}$, with girls being more economical than boys. This difference was more apparent at higher speeds. In another study involving pre-pubescent boys and girls, the girls had lower VO_2 (by 1 $ml \cdot kg^{-1} \cdot min^{-1}$) during walking than boys [83]. It is questionable whether this mean difference has biological significance, as measurement error for VO_2 is approximately 2 $ml \cdot kg^{-1} \cdot min^{-1}$ [29].

Astrand [4] was the first to show a gender difference in economy during childhood and adolescence. The difference of 1-3 $ml \cdot kg^{-1} \cdot min^{-1}$ was not apparent until higher treadmill speeds of 6.8-8.7 mph were achieved. He noted that although the girls performed at a higher percentage of their VO_{2max} they were still more economical than the boys.

Only one longitudinal study in which gender differences were examined was found [2]. Girls had lower VO_2 than boys by 1-2 $ml \cdot kg^{-1} \cdot min^{-1}$, but the authors also pointed out that the girls worked at a higher percentage of VO_{2max} than the boys. Thus, the girls had better economy despite being closer to their aerobic capacities. It is questionable whether the small amount of difference found had biological significance.

Studies that have shown no gender difference in economy vary in their designs. Some have included samples of pre-pubescent children [23, 43], while others used pubescent or post-pubescent children [42, 64]. Some studies have been designed to examine walking economy [23 64], while others examined running economy or a combination of walking and running [42 43].

Body size and economy

Body size may play an important role in walking and running economy. It is common knowledge in the field of biology that smaller animals use more oxygen relative to body mass, both at rest and at maximal exercise, than larger animals [66]. According to the surface law, animals generate heat according to surface area instead of body mass [66], resulting in larger animals having a lower surface area:mass ratio than smaller animals.

Rowland [66] has speculated that since children have a greater surface area to body mass ratio than adults, they are at an energy disadvantage because they must produce more energy in order to make up for that which is lost to the environment.

Overweight and obesity may also affect economy. Bailey and Pate [5] have suggested that segmental mass distribution may be an important factor in energy expenditure and indicated that adding mass to the trunk may improve economy. Support for this idea was provided by Pate et al. who found heavier runners were more economical than lighter ones in a study involving 20-60 year-old adults [58].

Child-adult exercise economy differences in pre-pubescent males [69] and pre-menarcheal females [71] have been accounted for when VO_2 is expressed relative to body surface area rather than weight. In a study where adolescent girls and young women were matched for height and weight (thus having no difference in body surface area), economy differences persisted when participants were compared relative to body surface area [1]. Despite this evidence, one should consider that an individual displaces his or her body mass, rather than surface area, during exercise.

Researchers have focused on obese children in two economy studies. In both studies, there was no difference in VO_2 (in $ml \cdot kg^{-1} . min^{-1}$) between obese and non-obese children. One study included pre-pubescent participants, and there was a 16 kg difference between the obese and non-obese children [43]. The other study included post-pubescent children, and there was a 24 kg difference between the obese and non-obese groups [68]. There were no height differences between participants in either study. The first study included participants who walked on the treadmill at an 8% grade [68], while the other included participants who walked and ran at 11 different treadmill speeds [43]. Thus, the existing literature shows that excess body weight may improve economy in adults, yet have no effect on economy in children. Without more data it is difficult to make a conclusion about the relationship between overweight/obesity and economy.

Maturation

The process of maturation most likely plays a major role in economy differences between children and adults. According to Malina [50], "the influence of maturity status on submaximal exercise capacity is mediated almost entirely by the effects of maturity status on body mass, which in turn is closely related to the size of the heart and skeletal muscle mass". Unfortunately, it is difficult to assess maturation because it varies in both timing (when it occurs) and tempo (the rate at which it occurs). Most researchers do not attempt to account for maturation in their analyses because of the variation. It is likely that maturation of various body systems could be involved in economy, but there is no real evidence to support this notion.

Most studies in which researchers have examined exercise economy in children have not included assessment of maturity indicators. In some studies with young children, researchers have avoided the issue of maturity status by assuming their participants were pre-pubertal [19, 24]. In others, researchers have classified participants based on menarcheal status [1, 71]. It is not entirely correct to assume a given pubertal status based on menarche because it is a late pubertal event [50]. A pre-menarcheal girl could easily have begun to reach pubescence, and a post-menarcheal girl is not necessarily fully mature.

Rowland has considered maturity in his studies by using the criteria set by Tanner to determine sexual maturation of participants. Tanner's criteria [73] are based on both pubic hair and genital development. Rowland used only the pubic hair criteria in his studies, but he included facial hair assessment as well [64, 69, 70]. Further, Rowland used parental assessment of pubic hair in two studies [64, 69]. In the other study, pubic hair development was determined by the children themselves or by parents. Although assessment of sexual maturation using Tanner's criteria can be arbitrary [50], it is better to consider maturation rather than ignore it.

Pulmonary parameters

Children ventilate more than adults for each liter of oxygen consumed during submaximal and maximal exercise [67]. This ratio of ventilation to oxygen consumption, also known as ventilatory equivalent for oxygen (VE/VO_2), has been shown to decrease with age [66]. The greater ventilation during childhood is usually due to a higher respiratory rate coupled with a lower tidal volume relative to body weight [66]. There is empirical evidence showing higher respiratory rate and higher VE/VO_2 in children versus adults [69, 71]. According to Dempsey [17], the oxygen cost of increased respiratory rate can average 3-5% of total body VO_2 during moderate exercise and 8-10% at VO_{2max}. Further, there is evidence that obese children show an increase in ventilation without the corresponding difference in ventilatory equivalent for oxygen [43]. This suggests that size is related to ventilation. However, a significant difference in ventilation has been found in girls and women matched for height and weight [1], suggesting that in addition to size, age may affect ventilation.

Armon et al [3] and Cooper et al [15] have suggested that children's higher sensitivity to CO_2 than adults may be a mechanism for these respiratory differences. It is likely that ventilation may account for a portion of the economy difference seen between children and adults. However, no researchers have measured pulmonary function (e.g., forced vital capacity, maximal voluntary ventilation) in children versus adults to see if differences are related to economy. Since lung volume and function have not been shown to limit aerobic exercise capacity in healthy individuals, it is unlikely that pulmonary function would be related to economy.

Cardiac function

Turley and Wilmore [75] reported that cardiac output is lower in pre-pubertal children than adults during submaximal exercise at the same workload on both treadmill and cycle ergometer. They indicated that the primary reason for the lower cardiac output was a lower stroke volume, despite a higher heart rate (HR) in children compared to the adults. Rowland [66] has also found that children have lower stroke volumes than adults when comparing individuals ages 6-25.

Heart rate is another factor involved in cardiac output. It appears that HR at a given workload decreases as children age [67]. Rowland [65] showed a higher HR and lower stroke volume in pre-menarcheal girls versus women, but the difference in stroke volume was not statistically significant. Other studies have shown higher HRs (compared to adults) for a given submaximal workload in pre-pubertal [78] and pre-menarcheal [71] children, as well as post-menarcheal girls [1].

One longitudinal study involving pre-pubescent children (who were still pre-pubescent at the end of the study) indicated that HR at a given workload decreased with age [23]. Another longitudinal study involving pre-pubescent children indicated that girls had higher HRs at a given workload than boys [63]. Further, obese, pre-pubescent boys and girls were found to have higher heart rates than non-obese children at a submaximal workload [43]. Regardless of HR and stroke volume differences, if one calculates how much energy is consumed by the myocardium during exercise, the differences found in these studies are likely to be small (<1 $ml \cdot kg^{-1} \cdot min^{-1}$) and not contribute significantly to total body VO_2 [1, 33, 65, 75].

Resting energy expenditure

Resting energy expenditure related to body size declines with age [67], and researchers have hypothesized that it may be a factor in exercise economy differences. Maffeis et al found that obese, pre-pubescent children appeared to have higher absolute resting metabolic rate than non-obese children, but the difference disappeared when the value was expressed with respect to kilograms of fat-free mass [43]. MacDougall et al. [42] determined that resting energy expenditure could only account for 1-2 $ml \cdot kg^{-1} \cdot min^{-1}$ of the economy difference between children and adolescents. A difference of 0.5 $ml \cdot kg^{-1} \cdot min^{-1}$ was found between post-menarcheal, adolescent girls and women in another study [1]. Thus, it appears that resting energy expenditure may account for only a small portion of economy differences.

Substrate Utilization

Greater oxygen consumption is required to metabolize fat compared to carbohydrate, and there is some evidence suggesting that children may rely more on fat as an energy substrate during exercise than adults [67]. This could be a factor in why children use more oxygen at a given workload (are less economical) than adults. Pre-pubertal male children, ages 9-13, were found to use more fat than adults ages 23-33 in a cross-sectional study examining child-adult differences in economy [69]. The amount of fat metabolized during exercise is typically estimated by examining respiratory exchange ratio (R) values measured during indirect calorimetry . Rowland et al. found that children had lower R values at the same submaximal intensity (which was also the same percent of VO_{2max} as the adults) and at maximal exercise. However, in another cross-sectional study, post-menarcheal girls and women of equal size were found to have no difference in substrate utilization (based on R values) [1]. Results from a longitudinal study involving pre-pubescent children (ages 7-10 years) indicated that there was no difference in substrate utilization at a given workload [23]. Results from another longitudinal study of prepubescent children indicated that girls use more carbohydrate than boys at a given submaximal workload [62]. However, the girls performed at a higher percent of their VO_{2max} and did not differ significantly from the boys in economy. Based on these studies it is unclear if substrate utilization contributes to the economy differences in children versus adults.

Running mechanics

In two different studies comparing economy in pre-pubescent and pre-menarcheal children versus adults, Rowland and colleagues found that greater stride frequency in children appeared to contribute to higher VO_2 during exercise [69, 71]. Unnithan and Eston [78] also determined that greater stride frequency contributed to a higher energy cost of exercise in pre-pubertal boys, compared to men. In 1954, Astrand [4] was the first to postulate that an increased stride frequency in children may be responsible for higher VO_2. Several researchers after him have also come to this conclusion. In a cross-sectional study involving children ages 7-16 years, MacDougall et al. [42] found that height (and ostensibly, stride frequency and stride length) was partially related to economy differences. However, MacDougall et al. did not actually count stride frequency. They assumed that stride frequency would be lower in taller individuals. However, in a study comparing girls and women matched for height and weight, the authors found no differences in stride frequency [1], despite the fact that the girls were less economical than the women.

Other gait-related characteristics could be partially responsible for economy differences between children and adults. Martin and Morgan [51] suggested that ground reaction force may affect economy. Ground reaction force reflects the net effect of muscular action and segment accelerations while the body is in contact with the ground[51]. The authors suggested that, compared to rear foot strikers, individuals who strike the ground more forward on the foot may rely more on musculature to assist with cushioning. However, there are no data to support this theory as it relates to running economy in children. A similar concept was examined in a study where researchers studied muscular efficiency in children and adolescents [30]. The authors calculated efficiency as the ratio of work rate to VO_2. They found that muscular efficiency increased with age in a sample of boys ages 7-15. Their protocol involved having the boys walk uphill on a treadmill. The researchers also found no relationship between submaximal VO_2 and leg length, but stride frequency was not measured.

Cocontraction is the simultaneous activation of agonist and antagonist muscles during a task [26], and has been implicated as a possible factor for poorer economy in children than adults. Frost et al. [26] found that younger children experienced more cocontraction than older children. However, results from another study indicated that 11-14 year-old children displayed gait patterns similar to those found in adults [28]. Thus, there may be issues related to walking and running mechanics that are responsible for economy differences.

Training

Training status may play a role in submaximal exercise economy in children, but research in this area is limited, and results are equivocal. Some researchers have found no economy difference between fit individuals and less fit individuals [36, 79], although Unnithan et al. [79] did find a difference in HR, R, and RPE between trained and untrained participants. On the other hand, researchers have found that age and training status appear to have a combined effect on economy [16, 35]. More research is needed in this area in order to separate the effects of exercise and sports training from normal growth and maturation.

Other factors

Other factors to consider when examining economy are allometric scaling, reliability of VO_2 measurements, and treadmill habituation. Allometric scaling is defined as a means of evaluating structural and functional consequences of changes in size of animals [67]. Resting metabolic rate relative to body weight increases as size of the animal decreases [67]. Differences in weight between an elephant and a mouse could vary as much as a factor of 10^7, but the difference in weight between a human adult and child might only be a factor of 10 [65 67]. Allometric scaling allows researchers to examine relationships through manipulation of scaling exponents instead of the typical ratio standard (expressing VO_2 relative to body mass). The classic use of allometric equations involves the equation $Y=a(X^b)$, with X representing body weight.

Different exponents (representing the variable b in the equation) have been suggested as appropriate to use when scaling data. Two commonly reported values are 0.67 and 0.75 [62]. Rogers et al. [62] attempted to determine appropriate scaling factors for pediatric data during submaximal and maximal exercise. They tested both the 0.67 and 0.75 exponents in addition to the typical ratio standard method and body surface area. The authors determined use of a body surface ratio ($ml \cdot m^{-2} \cdot min^{-1}$) or the 0.67 exponent ($ml \cdot kg^{-.67} \cdot min^{-1}$) was a more appropriate way to express VO_2 independent of size compared to the typical ratio standard method ($ml \cdot kg^{-1} \cdot min^{-1}$). Ebbeling et al. [19] also implied that the body surface ratio may be superior to the typical ratio standard. However, the assumption often made when using allometric scaling is that growth of body segments is isometric, which is not the case in children. Further, there is not consensus for a given scaling factor that always works with children or adolescents at a particular age.

Another issue to consider is if a single VO_2 measure can describe the exercise response reliably. Rogers et al. [63] examined reliability of VO_2 in children ages 7-9. Participants ran at steady-state at two different treadmill speeds, and reliability coefficients were higher for two trials (0.84-0.86) than they were for a single trial (0.72-0.75). In another reliability study involving walking in girls ages 5-10, one trial was found to be sufficient, despite the fact that the repeat measurements were taken six weeks apart (coefficient of variation was 12.4%). Morgan [55] has suggested that if the experimental setting is well-controlled, a single measure is adequate if group economy scores are of interest and the subject pool is sufficiently large.

An issue closely tied to reliability is treadmill accommodation versus habituation. Researchers have suggested that participants should undergo practice sessions on the treadmill prior to measuring economy. Frost et al. [25] suggested the two adjustments made when acclimating to treadmill exercise are accommodation and habituation. Accommodation refers to the development of a stable gait pattern, while habituation refers to lack of between-day or within-day differences. The authors tested children ages 7-11 during both walking and running on treadmill. Differences in VO_2 across trials were not found to be significant, and the authors concluded that multiple trials across multiple days did not necessarily improve stability of metabolic or kinematic variables, which refers to accommodation. Morgan has suggested that 10-60 minutes of treadmill habituation could be necessary prior to data collection [55].

Summary

Many factors can contribute to exercise economy in individuals. The evidence shows a distinct difference between children and adults in exercise economy, with children being less economical. Although researchers have examined reasons for child-adult differences, it remains unclear at what point between childhood and adulthood these differences begin to disappear. It is likely that maturation plays a role in economy differences, but researchers have frequently avoided the topic. Arguments can be made for body size, pulmonary function, cardiac function, substrate utilization, and stride frequency all playing a role in child-adult economy differences. However, we recently found that none of these factors contributed to the economy difference between adolescent girls and women matched for size [1]. Further studies are needed to determine the cause of the economy differences.

RATING OF PERCEIVED EXERTION

Perceived exertion has been defined as the ability to detect and respond to sensations that arise as a result of physiologic responses to exercise [57]. An individual's cognitive awareness of these sensations is considered to be a form of biofeedback in which central, peripheral, and metabolic changes during exercise are assimilated. Borg designed the first RPE scale and concluded that it was the best indicator of degree of physical strain [13]. In addition, Borg asserts that perceived exertion can be used to study "individuals at work or in leisure time, in diagnostic or clinical situations, and in epidemiological evaluation of daily exercise intensities" [13]. It is possible that the decline in participation in leisure time physical activities from childhood to adulthood is related to an individual's perceptions of exertion [7].

Borg's RPE category scale was designed to increase linearly with exercise intensity for work on a cycle ergometer [13]. Scale values range from 6 to 20. There are also verbal descriptions associated with the odd numbered values (see Appendix A). The scale was devised originally for use with adult males, and each number value on the scale is meant to correspond to HRs ranging from 60-200 $b \cdot min^{-1}$ (e.g., an RPE score of 14 would correspond to an HR of 140 $b \cdot min^{-1}$). Many researchers and practitioners use the RPE scale on a regular basis [13], but Borg himself admitted "there may not be one perfect scale for all kinds of subjective intensities in all kinds of situations" [13].

The concept of RPE specific to children has not been well-studied [40]. Some researchers have questioned the use of the traditional Borg scale in children and adolescents [20, 41, 54, 85], while others seem to think it is adequate for use with these populations [22, 61, 86]. In addition, Bar-Or found that obese children report higher RPE than non-obese at the same workload [9]. He hypothesized the difference in perception may be related to the fact that obese children are less physically active than the non-obese. There are several issues to consider when assessing use of RPE in children and adolescents. Exercise mode and intensity, measurement issues, and development of new, child-specific scales must be considered when evaluating RPE in children.

Exercise mode and intensity

Researchers have chosen cycle ergometry as the exercise mode in approximately half the studies examining RPE in children. Bar-Or can be considered one of the pioneers of RPE research in children [40], and he used the cycle ergometer in many of his early investigations. He cited two main RPE differences between children and adults as a result of his research. First, children assign lower ratings at a given workload than adults and second, children's RPE scores for a given workload appear to decrease faster than those of adults following aerobic training and heat acclimatization [7]. He based these conclusions on a series of eight studies of 7-68 year old males. Research protocols involved submaximal cycle ergometer exercise in which both HR and RPE were measured. Bar-Or reported that younger participants gave lower RPE scores at a given HR (4-4.5 point difference), even when values were expressed as percent of HR max. This represents a large difference between younger and older participants. Thus, Bar-Or concluded that Borg's idea to multiply RPE level by 10 to estimate HR does not hold true for children, adolescents, or young adults.

Bar-Or also concluded that during training, children decrease their RPE response (at a given workload) faster than adults [7]. Bar-Or's study participants were grouped by 10-year age increments. He plotted the correlation between RPE and HR versus the age groups. Based on his analysis, Bar-Or speculated that either adults describe their exertion levels less accurately than children, or children can better or more honestly perceive changes in physiological strain than adults. Bar-Or noted that HR can decrease as a function of training, but he stated that reduction in RPE following training was above and beyond that of the HR.

There are two studies that have compared RPE assessments in pre-pubertal boys versus men at ventilatory threshold [44, 45]. Participants in the first study [44] completed a cycle ergometer VO_{2max} test, during which ventilatory threshold was determined. In subsequent testing bouts, participants exercised at 80%, 100%, and 120% of ventilatory threshold and reported RPE at each intensity. No difference in RPE was found between boys and men. However, the researchers admitted that the negative results may have been due to low power because of small sample size (9 boys and 9 men).

The second ventilatory threshold study also involved a cycle ergometer VO_{2max} test [45]. In this study, children reported higher RPE at ventilatory threshold than adults. However, the authors noted that ventilatory threshold occurred at the same percent of VO_{2max} in both children and adults. HR was higher in children than adults at ventilatory threshold, which may partially explain their higher RPE values.

A third study involved measuring RPE ventilatory threshold during treadmill exercise, rather than cycle ergometry, in pre-pubertal boys only [46]. The children reported a wide range of RPE values at ventilatory threshold, but the numbers were lower than those reported previously by adults. The authors noted this may be important because ventilatory threshold usually occurs at a higher percent of VO_{2max} in children compared to adults.

Another study including pre-pubescent boys involved comparison of RPE during three different treadmill protocols [47]. Participants reported higher RPE at maximal exercise performed by walking than for a running or combination run/walk protocol. Although the RPE was higher, VO_{2max} was lower during the walking protocol. Results from this study indicate that the higher RPE in the walking protocol may be due to leg fatigue or protocol length since treadmill elevation was very steep by test end.

Other investigators studying RPE have compared children and adolescents during cycle ergometer exercise. Williams et al studied children/adolescents, ages 11-14 years[86]. The children first completed a submaximal exercise test that was used to predict VO_{2max} and familiarize them with the Borg RPE scale. Participants were instructed in a subsequent exercise bout to work at RPE levels corresponding to 9, 13, and 17. The authors concluded the participants understood the RPE scale since HR increased significantly with each increasing workload.

Eston and Williams [22] assessed RPE at power outputs corresponding to 30%, 60%, and 90% of predicted VO_{2max} and found that the 15-17 year old participants were able to use the Borg scale correctly. RPE, HR and power output had linear relationships with each other, with correlations ranging from r=0.74-0.78. Power outputs were set based on percentages of predicted, rather than measured VO_{2max}, so it is questionable whether the participants were truly exercising at the intensities the authors cited. Regardless of what the true exercise intensities may have been, the linear relationships found among RPE and HR most likely were not affected.

Measurement issues

Reliability, validity, and study design/statistical issues must be considered when studying RPE measures. Most investigators have found the Borg scale to be reliable for use with children and adolescents. Mahon and Marsh measured test-retest reliability of RPE at ventilatory threshold during treadmill exercise in pre-pubertal children [46]. The correlation between trials, which were 2-16 days apart, was r=0.78. The mean RPE at ventilatory threshold was slightly but significantly higher during the first trial. The authors noted that there was large inter-individual variation in RPE, which was not due to differences in ventilatory threshold. They concluded researchers should use RPE with caution in children ages 8-12, despite the moderately high correlation coefficient.

Bar-Or and Ward examined test-retest reliability in two studies that included different groups of adolescent, obese children [10,77]. In the first study, the investigators found a correlation coefficient of r=0.92 (averaged across all exercise intensities) for 11 obese adolescents [81]. In the second study, they found a correlation of r=0.59 at the lowest exercise intensity (20% of VO_{2max}) and r=0.89 at the highest exercise intensity (80% of VO_{2max}) [10]. Thus, RPE might be a better predictor of exercise intensity at higher exercise workloads.

Lamb et al questioned the use of traditional methods of correlation coefficients to determine reliability (repeatability) of RPE measurements [41]. The authors used a technique called limits of agreement suggested by Bland and Altman [12] to assess reliability of their data, as well as the typical Pearson interclass and ANOVA intraclass correlation techniques. Participants were college-age men who completed two identical treadmill protocols, 2-5 days apart. Results of the correlation analysis revealed test-retest reliabilities ranging from r=0.60-0.81 (Pearson correlation) and from r=0.75-0.82 (intraclass correlation). For both analyses, the correlation coefficients declined as exercise intensity increased. Limits of agreement results indicated variability in test-retest results of up to 3 RPE units and the same trend of higher variability in response as exercise intensity increased. The authors concluded that the Borg 15-point RPE scale may not have good test-retest reliability. However, results from correlation analysis followed the same trends as the limits of agreement method, suggesting that the analytic methods were of similar quality.

Validity is another important measurement issue, which is more important than reliability. There are two methods researchers have used to validate RPE in children and adolescents. One method is to compare it to HR, and the other is to test the participants' ability to set exercise intensity to a given RPE level. RPE and HR are both considered to be linearly related to workload[7]. Validating RPE with HR involves checking to see if this linear relationship holds true. On the other hand, if one holds a work output to a given RPE level, then changes in RPE should be directly related to the corresponding HR. Only one study was found in which validity of RPE was assessed in a sample including pre-pubescent children only. All other studies of youth included both children and adolescents. McManus et al. [54] included prepubescent children (classified as such by Tanner's criteria for pubic hair and genital development) in a study consisting of 3-minute treadmill exercise stages. Significant correlations between HR and RPE, ranging from r=0.20-0.28, were found in the second, third, and fourth exercise stages, and it appeared that the children underestimated their exercise intensities. Despite the fact that the correlation coefficients were statistically significant, values were low, leaving it questionable whether RPE assessment is valid in pre-pubescent children. In fact, Robertson and Noble [61] speculated there may be a critical age threshold involved with RPE validity. Due to lack of evidence, they are not sure what the age threshold should be.

In studies that include older children and adolescents as participants, validity coefficients have been higher than those reported in studies including pre-pubescent children. Bar-Or [7] conducted a series of studies including participants ages 7-68 years. All participants completed a submaximal cycle ergometer test, with different workloads used for individuals of different age groups. Bar-Or reported correlations between RPE and HR in individuals ages 7-20 ranging from 0.70 - 0.88 during cycle ergometer exercise. Gillach et al. [27] examined the relationship between RPE and HR in participants ages 11-14 years versus adults. Sessions were performed two times, one year apart, using cycle ergometry as the exercise modality. When the researchers examined the data with respect to the mean of individual correlations, the relationship between RPE and HR in children was r=0.92 for the first testing session and r= 0.94 for the second. When Gillach et al. examined the data based on group means, the correlations between RPE and HR in children were r=0.64 for the first test and r=0.65 for the second. The authors reported that there was a wide range of HRs for a given RPE level. These results led the authors to conclude that RPE is good for monitoring changes in exercise intensity, but they were not sure whether it helped predict level of physical strain. This study had two major limitations. The first is that the testing periods were a year apart, which introduces the possibility that the children's RPE would change as a function of age. The second limitation is that the exercise stages in the cycle protocol were only two minutes. Thus, if metabolic steady-state is crucial for RPE validity, it is questionable whether participants achieved this during the various exercise stages.

In another study, Eston and Williams [22] explored the validity of RPE using HR as a criterion measure. Their study participants were 15-17 years old. The protocol involved two cycle ergometer tests that had three different submaximal exercise intensities. The relationship between RPE and HR was significant ($r=0.74$, $P<0.01$), as was the relationship between RPE and power output ($r=0.78$, $P<0.01$).

Two studies involved children/adolescents performing exercise at levels 7, 10, 13, and 16 [80 82] on the 6-20 Borg scale, all using the same protocol. The protocol was set in two stages. The first stage required participants to perform a cycle ergometer test including four submaximal exercise intensities and an aerobic capacity test. The second stage required participants to exercise at RPE levels 7, 10, 13, and 16 on both cycle ergometer and a walking track. One study included overweight children/adolescents [80], ages 9-15, and the other compared children/adolescents ages 8-14 to adults [82]. Overweight children (30-38% fat via skinfolds) were able to discriminate the different RPE levels accurately on the cycle ergometer [80], but they overestimated (they indicated a higher intensity than the required level) RPE during the track exercise. The differences between HRs on cycle and track at RPE levels 7, 10, 13, and 16 were 30, 36, 32, and 28 $b \cdot min^{-1}$, respectively, with the track HRs higher at every RPE level. The authors concluded that overweight children need additional instruction prior to using the Borg scale. However, the authors were comparing RPE in overweight youth during a non-weight-bearing versus a weight-bearing exercise activity, with the non-weight-bearing activity as their criterion measure. Overweight children may give higher RPE during weight-bearing exercise due to the nature of the activity. Thus, the true meaning of study results may be questionable.

In the other study using the same protocol [82], children/adolescents and adults were found to be similar in their abilities to reproduce cycle intensity at a given RPE level. Also, both groups overestimated (overexerted) during the track exercise compared to their original cycle ergometer test. Adults were better able to estimate the prescribed intensity level close to the value established in the submaximal cycle ergometer test compared to the children. The authors expected that children would overexert themselves at the various RPE levels because children typically report lower RPE for a given workload [7]. However, the children under-exerted themselves instead. Again, one should question the use of a non-weight-bearing mode of exercise as the criterion when comparing it to weight-bearing exercise.

In another study, children/adolescents were asked to work at exercise intensities corresponding to RPE levels of 9, 13, and 17 [86]. Study participants, ages 11-14, performed a graded exercise test that was used to predict aerobic capacity. In a subsequent exercise bout (2-3 weeks later), children were required to reproduce RPE levels of 9, 13, and 17. Results showed that the children were able to produce the appropriate exercise intensity at given RPE levels and that the children had higher HRs than would normally be expected based on RPE level (e.g., HRs at RPE level 9 were higher than the expected 90 $b \cdot min^{-1}$). It is important to note that the previously mentioned study designs did not include workload randomization. Randomizing may have given a better indication of the children's abilities, since performing the workloads in the order of increasing intensity gives the children a point of reference.

In summary, it appears that, the RPE scale may be more valid in older children and adolescents, compared to younger children. It is interesting to note that only one study examining RPE in children and adolescents accounted for pubertal status. Although emotional and physical maturation may not occur at the same time, it appears that some type of maturation assessment would be helpful when determining the reliability and validity of a particular RPE scale.

There are other factors to consider when determining the validity of RPE assessments, as highlighted in a review by Dishman[18]. He notes that there is consensus regarding the fact low-intensity RPE assessments by adults seem to be governed by local factors (e.g., muscle sensation). With increasing exercise intensity, central factors (e.g., increase in blood lactate, hyperventilation) play a more significant role. He also states that RPE and relative VO_2 correspond at all exercise intensities independent of exercise mode and indicates that VO_2 may be a better criterion measure than HR when determining RPE validity. It is important to note that the association of $\%VO_{2peak}$ and RPE can change based on fitness level and that RPE may more closely linked with $\%VO_{2peak}$ after training in adults[18]. It is unknown what effect fitness level and/or training may have on RPE assessment in children. It appears to be clear that the use of both VO_2 and HR as potential criterion measures for RPE assessment is warranted.

Development of child-specific scales

Due to concerns about use of the traditional Borg scale in a pediatric population, researchers have developed child-specific instruments that measure RPE. The Children's Effort Rating Table (CERT) [85], the OMNI Perceived Exertion Scale [60], and the Cart and Load Effort Rating (CALER) Scale [21] are three such scales. None of these scales have had adequate testing for reliability and validity in both child and adolescent populations. The literature that exists to date will be discussed in the following paragraphs.

Williams et al. [85] developed the CERT scale for use with children, ages 6-9. Derivation of the CERT followed several steps. First, children ages 5-9 were initiated to walking and running on a treadmill, stepping on a bench, and pedaling a cycle ergometer. HR was measured during all activities, and the children were asked about their exercise perceptions, including their understanding of the Borg scale. Next, a different group of children performed running, walking, and jumping rope at different speeds and time periods outside on the playground. After the activities, the children were asked to describe their efforts, using pictures and words. Based on the children's responses, the CERT was devised using phrases appropriate to their descriptions.

The CERT is somewhat similar to the Borg scale in design [20]. It has a numerical range of 1-10, with a verbal anchor corresponding to each number value (see Appendix B). The numeric RPE values are designed to correspond with HR, assuming a linear relationship between the two measures. The HR value is supposed to equal 100 plus 10 times the RPE value, resulting in a range of 110-200 b·min-1. The verbal anchors range from "very, very easy" to "so hard I'm going to stop". The authors contend that the wording for the CERT is more developmentally appropriate for children than what is found on the Borg scale.

The first CERT field test involved a stepping at different loading conditions, and the children described their RPE using the CERT. HRs were recorded during the testing period. The next phase of field testing involved children working at level 5 and 7 of the CERT while stepping, and HRs were again recorded. CERT ratings for a given intensity level decreased with age, but the relationships were not analyzed statistically. Also, children's HRs were higher than expected at CERT levels 5 and 7, but the authors attributed this result to unfamiliarity with the stepping task. The authors noted that this was their first round of testing using the CERT, and they later examined its reliability and validity.

When Eston et al. first tested reliability and validity of the CERT scale, they used cycle ergometry as the mode of exercise, and the participants were slightly older, ages 8-11 [20]. Children first performed an aerobic capacity test, with four-minute incremental stages. Participants' CERT RPE scores were measured at the end of each testing stage. The next testing phase involved the children cycling at intensities corresponding to levels 5, 7, and 9 (randomly ordered) on the CERT. The third phase was a repeat of the second, and used to estimate test-retest reliability. Results showed significant correlations between CERT RPE and HR (r=0.76) and CERT RPE and work output (r=0.75). Results also indicated that the work output values and HRs were lower than those predicted during the maximal test. Reliability coefficients for the test-retest trial stages ranged from r=0.91-0.97 for work output at the three CERT levels and ranged from r=0.65-0.86 for HR at the three CERT levels. The lowest correlation coefficients occurred for CERT level 9 for work output and CERT level 7 for HR. The authors concluded that the CERT was reliable and valid, but possible gender differences may exist.

After initial testing, the CERT reliability and validity were evaluated further on two occasions [38, 39]. The first test involved using both the CERT and Borg RPE scales [38]. Children 9-10 years old performed maximal exercise via cycle ergometer on two separate occasions and reported RPE based on either CERT or Borg scales (participants were randomly assigned to each group). Test-retest reliability over two trials for the CERT was r=0.91, and r=0.90 for the Borg scale. Validity coefficients for the relationship between perceived effort and both HR and power output ranged from r=0.90-0.98 for both RPE scales. The author suggested that either scale would be appropriate for use with 9-10 year old children.

Lamb performed a second reliability and validity study, which was an extension of the first, involving the same participants [39]. Participants were asked to reproduce specific RPE levels from whichever scale they had used in the previous investigation. This study was also conducted in two trials with cycle ergometer. Children in the CERT group were asked to exercise at levels of 3, 5, 7, and 9, while children in the RPE group were asked to exercise at levels of 8, 12, 15, and 18. The authors designed these CERT and RPE levels to be at comparable intensities. Results indicated that the group using the CERT had higher HRs and power outputs than the group using the Borg RPE scale. Validity coefficients were higher when RPE, using either CERT or Borg scales, was compared to power output, rather than HR. Test-retest reliability for HR and power output at given CERT and Borg RPE levels were poor. The reliability coefficients were also low for the lightest workload in the first study (r=0.43 for Borg and r=0.23 for CERT), but not as low as those in the second study (r=0.08 for Borg and r=0.10 for CERT). It is unclear why some of the reliability coefficients in the second study were lower than the first. However, the low coefficients corresponded to the lowest workloads, perhaps indicating that younger children can report RPE more reliably at higher workloads.

The OMNI scale was developed for use with male and female African American and Caucasian children ages 8-12 [60]. Robertson et al had a graphic artist design a series of four pictorial descriptors showing a child riding a bicycle uphill. Children were asked to describe the four pictures, which gave the scale's creators words to illustrate the different intensity levels. Six descriptions provided by the children were chosen to represent different exertion levels that matched up with the pictures. The descriptions corresponded to numbers placed along the scale, ranging from zero to 10 (see Appendix C).

When investigators tested the scale, they used a mixed race and sex sample of children. Participants completed a cycle ergometer test consisting of four steady-state exercise stages. HR was measured each minute of the test, and VO_2 was measured in the last minute of each exercise stage. RPE was measured via the OMNI scale in the last minute of each exercise stage. The investigators did not report any reliability testing associated with the scale, but they did report validity [60]. They used regression analysis to determine if there was a linear relationship between the OMNI RPE scores and both HR and VO_2. The r^2 values for the models for HR and VO_2 were 0.86 and 0.88, respectively. The authors concluded that participants were able to use the scale successfully, but noted that the response linearity may not apply all the way to VO_{2max} because the testing protocol did not involve the participants exercising to their aerobic capacities. The standard deviations ranged from 0.22-0.51 at the highest RPE levels reported, and the authors concluded that relationships between OMNI RPE and HR, and OMNI RPE and VO2 were linear. [60]. Further, it is questionable whether the scale is usable because instrument reliability is unknown.

The CALER scale was developed by the same researchers who devised the CERT[21]. The authors thought an RPE scale with pictures, as well as numbers and verbal anchors would be more appropriate for younger children. The authors did have knowledge of the OMNI scale, but chose to create their own. The CALER scale is similar to the OMNI scale, in that there is a picture of a child riding a bicycle at various stages of exertion (see Appendix D). The difference between the pictures in the two scales is that the CALER scale depicts the child pulling a cart that is progressively loaded with bricks. The number of bricks in the cart corresponds to the numbers on the scale, and the verbal anchors are five statements from the CERT. There is also a difference between the CALER and OMNI scales in the numeric choices. The OMNI scale has RPE levels from zero to ten, while the CALER has choices from one to ten.

Eston et al. [21] determined the reliability of the CALER scale but not the validity. Study participants were 7-10 year-old children who were asked to work at CALER levels of 2, 5, and 8 on the cycle ergometer. Each exercise stage lasted three minutes. The children participated in four trials. Correlation coefficients were higher between trials 3 and 4 than between the first 2 trials, suggesting that the instrument was more reliable after the children were able to practice. The authors concluded that the scale is reliable and valid for use with 7-10 year-old children. However, validity was never tested using physiological variables as criterion measures.

Summary

The use of RPE in children and adolescents has gained popularity with investigators over the last few years, most likely because it is potentially related to physical activity behavior. Reliability and validity studies of the traditional Borg 15-

point scale have not confirmed its usefulness with children or adolescents. Researchers have developed new scales in response to this uncertainty, but it is not clear if these instruments are more reliable or valid than the original Borg scale. Based on the data available so far, the OMNI scale has the most promise for use with child and adolescent populations, but more research is needed. In particular, it is important to determine at what age certain scales may be most appropriate since RPE use appears to be more valid in older children than in younger children. It is also important to ascertain which variables are best to use as criterion measures when determining validity of these scales.

CHAPTER 3

RUNNING ECONOMY IN ADOLESCENT GIRLS

ABSTRACT

The relationship between age and walking and running economy [submaximal oxygen consumption ($VO_{2submax}$)] in adolescent girls (n=58), ages 13-18 years, was examined in this investigation. Most participants were matched for height (158.8 ± 3.8 cm) and weight (54.8 ± 5.0 kg). A group of participants with higher body mass index (BMI) who fit the same height criteria were also recruited. Anthropometric measures (height, weight, sitting height, breadths, skinfolds) and pre-exercise $\dot{V}O_2$, as well as a habituation session, were obtained prior to a submaximal (consisting of 3 different stages) and maximal treadmill test. The primary purpose of this study was to determine if exercise economy improves with age in a cross-section of girls ages 13-18 years who were matched for size. The secondary purpose of this study was to determine the effect of higher BMI on the girls' economy. Results of repeated measures analysis of variance (ANOVA) showed that economy did not significantly improve with age in this sample. Stepwise linear regression showed that HR was the best predictor of economy in all three treadmill stages. Ventilation and body surface area were predictors of economy in the first and third treadmill stages. VO_{2max} was an additional predictor of economy in the first treadmill stage, and stride frequency was an additional predictor of economy in the third treadmill stage. There were not enough higher BMI participants to perform inferential statistics (n=4), but the higher BMI girls did not appear to differ from the normal BMI participants in economy. Results indicated that the running speed may have

resulted in the girls having inefficient running mechanics due to the above average fitness levels of the participants.

INTRODUCTION

Economy can be defined as the oxygen consumption (VO_2) required to perform submaximal, steady-state exercise at a given workload. The lower the VO_2 is, the better the economy. During submaximal exercise in children, a steady-state can usually be achieved within three to four minutes [67]. Economy has been documented as a factor influencing endurance performance, particularly among individuals of a similar aerobic capacity [35], and may also influence capacity to perform recreational and occupational physical activities [67].

Cross-sectional and longitudinal studies have shown that children are less economical (i.e., greater submaximal oxygen consumption) than adults, both at a given submaximal treadmill speed and grade [2, 69, 70, 78] and at a given relative percentage of aerobic capacity [35]. Also, there is some evidence that the difference between children and adults becomes larger with increased exercise intensity [71, 75]. The reason(s) for submaximal economy differences between children and adults remain(s) unclear, but researchers have suggested many factors that may be responsible. Body surface-to-mass ratio, ventilatory parameters, gait kinematics, cardiac function, and substrate utilization have all been implicated as factors that may affect economy. Several factors may be a result of size differences between study participants. In most economy studies comparing children/adolescents to adults, the adults are larger than their younger counterparts[65, 69-71]. Thus, researchers have not been able to discount size as a factor affecting economy.

To remove the effects of body size from consideration, we recently conducted a study [1] that included girls (ages 12-14 years) and women (ages 18-24 years) matched for stature and weight. Despite being matched for size, the girls used more oxygen per kilogram body weight (were less economical) than the women in both treadmill walking and jogging. The economy differences between girls and women in our study were somewhat less than those found in other studies[65, 71]. Also, the difference in economy between groups was greater for jogging than for walking. These results indicated that size explains only a portion of the difference in exercise economy between children and adults. We concluded that factors other than size contribute to the economy difference between girls and women.

We postulated that the reasons for the remaining difference in economy may be due to resting energy expenditure, myocardial oxygen consumption, or ventilation. We estimated that resting energy expenditure accounted for ~25% of the VO_2 difference during walking and ~11% of the difference during running. Based on previous research [33, 65, 75], we estimated that myocardial VO_2 due to higher heart rate (HR) values in the girls would not have added significantly to the total body VO_2. Also, higher ventilation during both walking and running (both due to higher respiratory rates) in the girls was not likely to have contributed much to the economy difference [17]. Further, there were no data available regarding the maturity status of the girls in our study, other than the fact that the girls were post-menarcheal. Having information about menstrual cycle regularity would give an indication of overall maturity status, since achievement of menarche does not represent complete maturity. Thus, the reasons for differences in economy between girls and women matched for size remain unclear.

An issue directly related to size differences is whether being overweight or obese affects submaximal energy expenditure. Bailey and Pate [5] suggested that segmental mass distribution may be an important factor in economy. They hypothesized that extra mass in the trunk region may improve economy, although it may not be beneficial from other standpoints. Indeed, Pate et al. [58] showed that heavier adult runners were more economical than lighter runners. However, obese youth have been shown to have no difference in walking economy expressed as VO_2 per kg body mass [68] or VO_2 per kg fat free mass [43] when compared to their non-obese counterparts.

Obese, pre-pubescent children were also found to have similar economy compared to their non-obese peers during running [43]. While there was no attempt to match for height in either study, there was no significant difference in height between the obese and non-obese participants. Neither study included stride frequency (or other gait parameters), or pulmonary function measures as possible contributors to energy expenditure. One might not expect a difference in gait or pulmonary function because the children were the same height, but it is unknown how being overweight may affect these variables.

Our recent study [1] showed that matching girls and women for size removed some of the difference in economy normally seen between children and adults. However, matching for size only removed part of the difference, which indicates there are other factors (e.g., maturity) involved. Based on our previous study, those factors must be related to changes that occur between the ages of 13-18 years. The primary purpose of this study was to determine if exercise economy improves with age in a cross-section of girls ages 13-18 years who were matched for size. The secondary purpose of this study was to determine the effect of higher BMI (same height range, but heavier in weight than the normal BMI participants) on the girls' economy.

METHODS

Participants. Study participants were post-menarcheal, adolescent girls, ages 13-18 years, who fit a particular range of height and weight criteria (N=58). Height and weight criteria were 156-164 cm and 48-57 kg, which are the same ranges used in our previous study [1]. These values represent slightly taller than average 13-year-olds, and average to slightly shorter than average height 17-year-olds, who fit within the 15-85th percentile range of body mass index (BMI) percentile rank according to CDC growth chart normative values [77]. In addition, an attempt was made to recruit a group of higher BMI girls. All participants in this group (N=4) had a BMI greater than the 85th percentile for girls of the same age [77]. The majority of participants were not trained distance runners, defined as running more than 10 miles per week. Girls who played on sports teams were not excluded. All participants except three played on at least one sports team (basketball, gymnastics, soccer, softball, swimming, tennis, and, track), despite an attempt to include non-athletes as well as athletes in the study.

Participants were recruited through contacts with a church youth group, daughters of Michigan State University employees, school teachers, and sport team coaches. Written assent to participate and parental consent were obtained for each participant (see Appendix E). This research was approved by the University Committee on Research Involving Human Subjects (UCRIHS) at Michigan State University (see Appendix F).

Study Protocol for Day One. Each participant was familiarized with the laboratory environment. Height and weight were measured, followed by pulmonary function testing that included an assessment of forced vital capacity (FVC) and maximal voluntary ventilation (MVV). Background information (including menstrual history, asked by a female investigator) was also obtained. Each participant participated in a treadmill habituation session, consisting of at least ten minutes at various speeds and grades.

Pulmonary Function Testing. Each participant was provided with a clean, disposable mouthpiece to place on the end of a hose attached to a spirometer (SensorMedics; Yorba Linda, CA). She was given instructions for how to perform the FVC and MVV protocols. The FVC test involved the participant breathing normally for a few seconds, followed by a maximal inspiration. Immediately after the inspiration, each participant was required to perform a forced, maximal exhalation, as quickly as possible. The MVV test involved the participant breathing as fast and forcefully as she could, for 12 seconds. Each test was performed at least two times, with the participant in a seated position. The average of the two trials was used for analytical purposes.

Background information. Each participant was asked some basic background questions including date of birth, age at menarche, and menstrual history for the last four months prior to study entry. Girls who could not recall their past four months of menstrual history were asked to track their cycles for the following few months. The menstrual history data provided information regarding cycle length, which was to be used as an indicator for maturity [11, 74]. Sexual maturity assessment using Tanner's criteria was not employed due to concerns that there would be little variation in maturity status between participants.

Treadmill Habituation. Each participant engaged in a practice bout of treadmill walking and jogging. Previous research [55] has shown that 10 minutes is usually adequate time for habituation to occur. More time was spent if the investigator felt it was necessary, or if the subject requested it. Expired gases were collected, and participants wore a heart rate telemetry belt (Polar; Seattle, WA) during this time period in order to familiarize them with wearing the chest strap and breathing through the one-way valve during actual testing.

Study Protocol for Day Two. Anthropometric measures were obtained, followed by the treadmill exercise test. In most cases, there was approximately a one-week time period between testing days, but in no more than 15 instances there were 2-4 weeks between laboratory visits.

Anthropometry. Height (without shoes) and sitting height were measured to the nearest 0.1 cm using a stadiometer that was calibrated with a steel tape measure of known length. Weight was measured to the nearest 0.1 kg on a kilo-pound beam balance that was calibrated with known weights certified by the Bureau of Standards. Biacromial and biiliac breadths were measured to the nearest 0.1 cm using a spreading caliper. Skinfolds were obtained at five sites: triceps, subscapular, suprailiac, thigh, and medial calf. Triplicate measures were taken and values recorded to the nearest 0.5 mm using a Lange caliper. All anthropometric measurements were taken by the same female investigator.

Treadmill test. During all phases of treadmill testing, participants wore heart rate monitors and breathed into a mouthpiece connected to a (SensorMedics 2900; Yorba Linda, CA) metabolic measurement cart for analysis of expired respiratory gases. Prior to beginning exercise, each participant sat in a chair on the treadmill for 10 minutes. Expired gases were collected during this time in order to provide an index of pre-exercise VO_2. Although this value represented a value higher than basal metabolic rate, it provided a value typical of each participant's resting energy expenditure. The girls were instructed to refrain from exercising and eating and drinking (except for water) three hours prior to the test. Participants typically wore t-shirts, shorts, and athletic shoes appropriate for treadmill exercise.

The first stage of the treadmill test involved walking at 2.0 mph, 0.0% grade for six minutes. In the second and third minutes, stride frequency for the minute was determined by counting the number of right foot heel strikes in 30 seconds and multiplying by two. Walking economy was calculated from the mean VO_2 during the final three minutes of the stage.

The second stage of the treadmill test involved walking at 3.0 mph, 5.0% grade for six minutes. In the second and third minutes, stride frequency was counted in the same manner as the first stage. Economy was calculated from the mean VO_2 during the final three minutes of the stage.

The third stage of the treadmill test involved jogging at 4.5 mph, 0.0% grade for six minutes. Again, stride frequency was counted in the second and third minutes of the stage in the same manner as outlined for the first stage. Running economy was calculated from the mean VO_2 during the final three minutes of the stage. Previous testing from our laboratory has shown that girls with the higher BMI values would be able to maintain a speed of 4.5 mph. Previous testing from our laboratory had also shown that a speed of 4.5 mph would most likely not be an awkward pace for the normal BMI group. Any participant who attempted to walk at this pace was asked to jog instead.

At the end of the 18 minutes of walking/running, speed remained at 4.5 mph and grade was increased 2.5% each minute until the participant reached volitional fatigue.

Criteria for reaching VO_{2max} included two of the following: 1) Respiratory exchange ratio (RER) > 1.0, 2) maximum heart rate > 95% age-predicted maximum, 3) plateau or decrease of VO_2 (< 2 $ml \cdot kg^{-1} \cdot min^{-1}$) during the final minute of the stage. Although the investigator verbally encouraged the participants to continue to run as long as possible, each subject decided when to terminate the test and indicated her desire to stop by grabbing the front bar of the treadmill. Three participants did not reach VO_{2max} according to our criteria, but this did not affect analysis of the economy data. Immediately, the treadmill speed and grade were decreased to 2.0 mph and 0.0% grade. The participant walked slowly until her HR fell below 120 $b \cdot min^{-1}$, at which point she came off the treadmill.

Statistical analysis. The outcome variable in this study was VO_2 during each stage. A power analysis revealed that 16 participants per group was necessary for assessment by analysis of variance (ANOVA), assuming an expected difference of 4.0 $ml \cdot kg^{-1} \cdot min^{-1}$, power of 0.8, alpha level of 0.5, and effect size of 1.0. Repeated measures ANOVA was used to determine if age affected economy during the three exercise stages. Further, stepwise linear regression analysis was used to determine which factors predicted walking and running economy. Three correlation matrices were run to determine which factors had the best relationship to VO_2 in the three economy stages of the treadmill protocol and to determine which factors might be related to each other (see Appendix G). Variables with the six highest correlations to VO_2 in each stage were entered into the regression analysis. Statistical software packages used were Statview SE (Abacus Concepts Inc., 1988) and JMP (SAS Institute Inc., 1996).

RESULTS

Anthropometric participant characteristics are reported in Table 3.1, and physiological data are reported in Table 3.2. The participants in this study, particularly the normal BMI girls, were fitter than average girls their age [67]. They also did not show the typical decline in VO2max with age normally seen across this age group [37] (see Figure 3.1). To determine the effect of age on economy, repeated measures ANOVA was run. The analysis revealed that age had no effect on economy in any of the exercise stages ($F = 0.45$, $P = 0.8$). Closer inspection of the data revealed that eight girls, across all ages, displayed poorer economy than the rest of the sample during the third treadmill stage (see Table 3.3 for characteristics). Eight girls did not represent enough to perform statistical tests, but inspection of the data showed negligible differences between them and the rest of the sample for the first two treadmill stages. There was a difference in HR between the eight girls and the rest of the sample during the third stage of the treadmill test.

Since age had no effect on economy, stepwise linear regression analysis was used to determine the factors affecting economy in 13-18 year old girls. Prior to data analysis, a correlation matrix was run for potential variables affecting economy during the first, second, and third stages of the treadmill test. The variables included in the correlation matrix were any which were potentially related to economy, based on the literature (see Appendix G). The variables with the six highest correlations to VO_2 during the three stages of the treadmill test were selected and placed into stepwise linear regression. The six highest correlations were used so that we did not include too many variables in the analysis for the number of participants.

Age was not highly correlated with VO_2 during any of the exercise stages (r=-0.10 for all three stages). The six variables placed into regression analysis for stage 1 were HR, V_E, VO_{2max}, body surface area (BSA), age at menarche, and BMI. Results of linear stepwise regression showed that four factors influenced economy during the first stage of the treadmill test: HR, VO_{2max}, V_E, and BSA (see Table 3.4 and Figure 3.2). However, the final model could only account for 55% of the variance in VO_2 during the first stage.

The six variables placed into regression analysis for stage 2 VO_2 were HR, age at menarche, body surface area, sitting height, MVV, and V_E (see Table 3.4 and Figure 3.2). The only variable that entered the model was HR, which represented 31% of the variance.

Table 3.1 Age and anthropometric characteristics

	Sample (N=58)		**High BMI** (N=4)	
	Mean	St. Dev.	Mean	St. Dev.
Age (years)	15.3	1.5	16.7	1.9
Age at menarche (years)	12.5	1.0	12.2	1.3
Height (cm)	158.8	3.8	160.3	3.1
Weight (kg)	54.8	5.0	72.3	5.6
BMI ($kg \cdot m^{-2}$)	21.7	1.9	28.2	2.4
Sum of skinfolds (mm)	77.6	15.2	112.9	13.1
Sitting height (cm)	84.6	2.6	85.6	2.5
Leg length (cm)	74.2	2.8	74.7	2.5
Sitting height:stature ratio	0.53	0.01	0.53	0.01
Biacromial breadth (cm)	35.2	1.5	37.0	1.3
Biiliac breadth (cm)	25.6	1.2	28.2	1.7
Body surface area (m^2)	1.55	0.08	1.76	0.07

NOTE: Median values for BMI and sum of skinfolds in the normal BMI group were 21.8 and 77.0, respectively. Values were 27.9 and 112.1 for the higher BMI group.

The six variables placed into regression analysis for stage 3 VO_2 were HR, VE, stride frequency, sitting height, BSA, and biiliac breadth. Results of stepwise linear regression showed that four factors influenced economy during the third stage of the treadmill test. Heart rate, V_E, stride frequency, and BSA all entered into the final model (see Table 3.4 and Figure 3.2). HR during the third stage of the treadmill test had the most influence on VO_2, accounting for 55% of the variance. Ventilation, BSA, and stride frequency all had a much smaller effect on economy, accounting for 7%, 8%, and 4% of the variance, respectively. Thus, the final model accounted for 74% of the variance during the third treadmill stage.

Despite a vigorous recruiting effort, it was difficult to find higher BMI girls who were willing to participate in the study. Only four higher BMI girls were included in the

Table 3.2 Physiological data at rest and during exercise

	Sample (N=58)		**High BMI** (N=4)	
	Mean	St. Dev.	Mean	St. Dev.
Rest				
Rest HR ($b \cdot min^{-1}$)	83	12.2	80	4.0
Rest VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	4.4	0.7	3.7	0.8
Maximal exercise				
VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	46.9	5.3	40.1	7.9
HR_{max} ($b \cdot min^{-1}$)	202	9.3	197	9.1
Stage 1				
HR ($b \cdot min^{-1}$)	104	12.6	102	7.0
VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	11.5	1.0	10.8	0.9
V_E ($L \cdot min^{-1}$)	17.6	2.2	19.7	0.9
$\%VO_{2max}$	24.7	3.0	27.4	4.0
Stride freq. ($steps \cdot min^{-1}$)	50	2.5	51	1.3
Stage 2				
HR ($b \cdot min^{-1}$)	136	15.0	137	11.2
VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	20.9	1.2	19.7	0.6
V_E ($L \cdot min^{-1}$)	30.5	4.0	35.1	2.4
$\%VO_{2max}$	45.2	5.9	51	10.8
Stride freq. ($steps \cdot min^{-1}$)	59	2.5	59	3.0
Stage 3				
HR ($b \cdot min^{-1}$)	168	17.4	172	16.4
VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	31.6	2.8	30.2	0.6
V_E ($L \cdot min^{-1}$)	49.8	9.0	59.8	6.8
$\%VO_{2max}$	68.3	10.5	77.7	16.9
Stride freq. ($steps \cdot min^{-1}$)	80	4.3	80	2.1

Table 3.3 Physiological differences in eight girls with poor economy

	Sample Mean	(N=50) St. Dev.	**Poorer Economy** Mean	(N=8) St. Dev.
Age (years)	15.1	1.5	16.1	1.5
Age at menarche (years)	12.5	1.0	12.7	0.6
BMI ($kg \cdot m^{-2}$)	21.8	1.9	21.3	1.6
VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	47.6	5.1	45.9	2.6
HR_{max} ($b \cdot min^{-1}$)	201	9.3	208	7.1
Rest				
Rest HR ($b \cdot min^{-1}$)	81	10.4	96	17.8
Rest VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	4.4	0.6	4.7	1.0
Stage 1				
HR ($b \cdot min^{-1}$)	102	10.6	120	15.3
VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	11.3	0.8	12.8	0.8
V_E ($L \cdot min^{-1}$)	17.2	2.2	19.2	1.7
Stride freq. ($steps \cdot min^{-1}$)	50	2.5	49	1.8
Stage 2				
HR ($b \cdot min^{-1}$)	133	13.1	155	15.3
VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	20.7	0.9	22.7	1.4
V_E ($L \cdot min^{-1}$)	29.6	3.8	33.5	3.1
Stride freq. ($steps \cdot min^{-1}$)	59	2.6	58	1.6
Stage 3				
HR ($b \cdot min^{-1}$)	165	16.1	188	12.1
VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	30.9	2.0	36.8	1.7
V_E ($L \cdot min^{-1}$)	47.1	7.5	61.2	6.0
Stride freq. ($steps \cdot min^{-1}$)	81	4.3	80	4.6

final sample, which did not allow for use of inferential statistics in analysis of their data. Tables 3.1 and 3.2 show the differences in anthropometric and economy data between the lower and higher BMI girls. The average age of the higher BMI girls was slightly older than that of the lower BMI girls, since three of them were 17 years old. The higher BMI girls were heavier and slightly taller than the lower BMI girls. They also had a greater sum of five skinfolds. The frame size of the higher BMI girls was slightly larger than that of the lower BMI girls, with both biacromial and biiliac breadths being greater. The higher BMI girls had higher V_E than the lower BMI girls during all three treadmill exercise stages. Finally, the higher BMI girls had slightly lower VO_2 values at rest and during the three exercise stages than the lower BMI girls, despite being at a higher percentage of their aerobic capacities.

Table 3.4 Results of linear stepwise regression analysis

Factor (N=58)	R	R Square	R Square Δ
Stage 1			
Stage 1 HR	.492	.242	.242
VO_{2max}	.628	.395	.153
Stage 1 V_E	.684	.468	.073
BSA	.739	.547	.079
Stage 2			
Stage 2 HR	.555	.308	.308
Stage 3			
Stage 3 HR	.742	.55	.55
Stage 3 V_E	.787	.619	.069
BSA	.838	.703	.084
Stride frequency	.861	.742	.039

DISCUSSION

The primary purpose of this study was to determine if exercise economy improves as a function of age in girls 13-18 years old. It was expected that a significant negative relationship would exist between age and VO_2. That is, as the girls' age increased, exercise economy would improve [2, 65, 69, 71]. Repeated measures ANOVA showed that there was no relationship between age and economy in our sample. The lack of relationship between age and economy was surprising. Further analysis showed that age was poorly correlated with economy during all stages of the treadmill test ($r= -0.10$ for all three stages, see Figure 3.2).

Once it was determined that there was a lack of relationship between age and economy, we searched for the factors that predicted economy using stepwise linear regression analysis. Age did not enter into any of the regression models for VO_2 during any submaximal treadmill stage. The best regression model came from stage three and accounted for 74% of the variance in VO_2. The four variables entering the model were HR, V_E, BSA, and stride frequency. It was expected that stage 3 would show the best model since researchers have shown that economy differences between children and adults increase with increasing exercise intensity[1, 70, 75]. The larger difference might allow for better comparisons among potential factors affecting economy.

Although stage three provided the best regression model, HR was found to be a predictor of VO_2 in the regression models from all three treadmill stages. HR accounted for 24% of the variance in stage one, 31% of the variance in stage two, and 55% of the variance in stage three and was the best overall predictor of economy. Thus, it appears that HR has more influence on economy as exercise intensity increases. The relationship between HR and VO_2 is well known as being linear[52], but the linearity of the relationship and the existence of the relationship do not explain the lack of relationship between age and economy.

V_E and BSA entered the regression models predicting VO_2 in both stage one and stage three. V_E accounted for 7% of the variance in the first and third treadmill stages. BSA accounted for 8% of the variance in stages one and three. Previous research has shown that adolescent girls ventilate more than women who are matched for body size [1] during submaximal treadmill exercise. However, according to calculations we performed based on the research of Dempsey [17], V_E most likely did not account for more than 1 $ml \cdot kg^{-1} \cdot min^{-1}$ of the economy difference in our previous study. BSA area may have had more of an effect on economy if the participants had not fit into the height and weight criteria used for this investigation, but it is important to note that it had an effect despite the matching.

The remaining variable that predicted economy in the third treadmill stage was stride frequency, which accounted for 4% of the variance. Previous research has shown that stride frequency in pre-pubertal children was greater than in adults [69, 71, 78]. We found only one investigation examining stride frequency differences between adolescents and adults, in which there were no differences in stride frequency between post-menarcheal girls and women [1]. The girls in the study were matched for height and weight, which may have removed a potential difference in stride frequency normally seen between children and adults. However, the girls in this study were also matched for height and weight.

The finding that age and economy were not related was unexpected. Upon closer inspection of the data, we found eight girls, across all ages, who displayed poorer economy than the rest of the sample during the third treadmill stage. The only remarkable characteristic displayed by the eight girls that was different from the rest of the sample was higher HR at rest, during the three economy stages, and at maximal exercise. HR was the best predictor of economy in all three treadmill stages for the overall sample. Kitamura et al.[33] showed that there is a good correlation between HR and myocardial VO_2. Based on rough calculations from Kitamura et al.'s paper, it appears that even the greatest HR difference of 23 $b \cdot min^{-1}$ would only account for approximately 0.2-0.3 $ml \cdot kg^{-1} \cdot min^{-1}$. Thus, it is doubtful that the increased HR in the eight girls could account for the difference in energy expenditure between the eight girls with poorer economy and the rest of the sample.

We believe the likely reason for the lack of relationship between age and economy in the third treadmill stage is running speed. Although there are no established "normal values" for VO_{2max}, our study participants showed greater than average fitness compared to other girls their age (2.6 $L \cdot min^{-1}$ vs. 2.0 $L \cdot min^{-1}$)[67]. Anecdotal evidence indicated that several girls wanted to walk at the 4.5 mph speed because it was a slow running pace for them. The slower pace was chosen so that girls of any fitness level would be able to participate throughout the entire protocol.

The slow jogging speed may have caused participants to use an inefficient gait pattern. Stride frequency was found to be a predictor of economy in the third treadmill stage, but there were no apparent differences in stride frequency between the eight girls with poorer economy and the rest of the sample for any of the treadmill stages. Rowland believes that the increased stride frequency in children versus adults is a result of shorter leg length in the children[66]. However, there was a poor correlation between leg length and stride frequency in all three treadmill stages ($r=<-0.23$, $r=-0.33$, and $r=-0.02$ for stages 1, 2, and 3, respectively). This could suggest that the speed, particularly during running, may have produced an inefficient gait pattern and masked any economy differences that might be present across the sample.

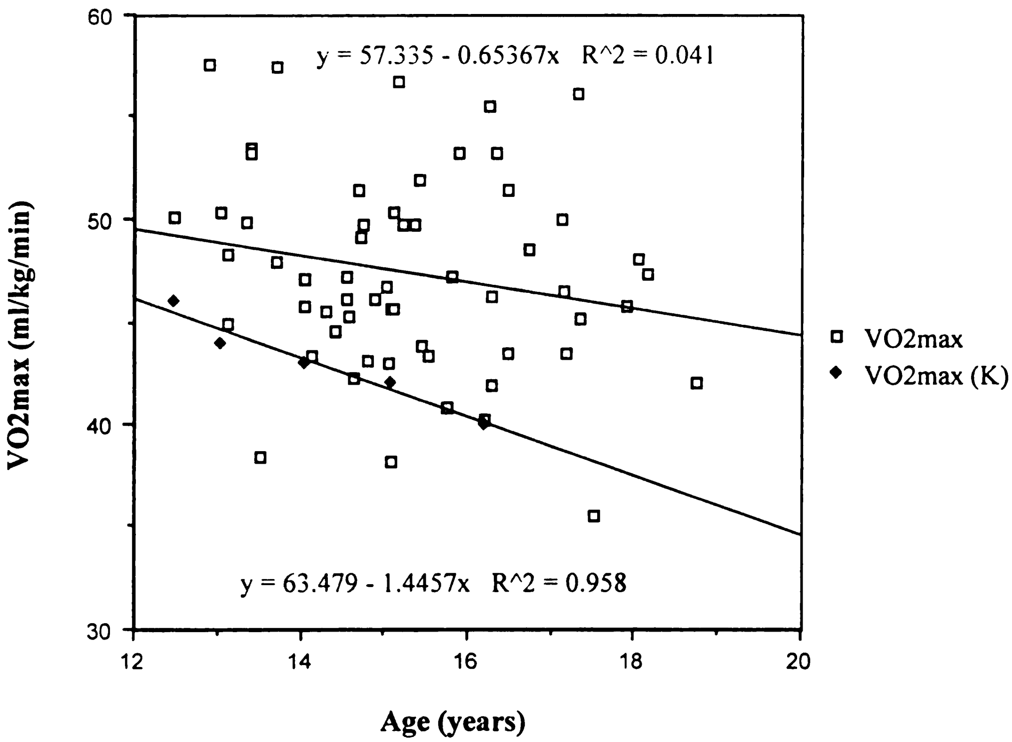
Our results may not surprise researchers who believe that child-adult differences in economy are related to body size [71]. Rowland [66] has speculated that individuals who have a greater surface area to body mass ratio may be at an energy disadvantage because they need to produce more energy in order to make up for that which is lost to the environment. BSA did fit into the first and third stage regression models, but it only explained 8% of the variance in each. This is most likely because our participants fit into a particular height and weight range, which did not allow much difference in BSA between participants. However, based on our previous research [1] we expected to remove all effects of body size and BSA by matching for height and weight, so that it would be easier to tease out other factors affecting economy.

The secondary purpose of this study was to determine the effect of BMI on economy. Unfortunately, only four girls with BMI above the 85th percentile [77] volunteered to participate, and inferential comparisons could not be made with the normal BMI girls due to lack of statistical power. From a descriptive standpoint, the higher BMI girls differed little from the normal BMI girls. The higher BMI girls were slightly taller, with larger biacromial and biiliac breadths than the normal BMI girls. Since they were taller and had larger lungs, the higher BMI girls had larger V_E than the normal BMI girls. The higher BMI girls also had slightly lower VO_2 values at rest and during exercise than the normal BMI girls. It is doubtful whether these differences were biologically significant, let alone statistically significant.

There were some limitations to this study. The sample population may have been biased due to the girls being recruited from a convenience sample. The participants were fitter than average girls their age, which may have affected economy. Although the literature appears divided regarding whether or not training status affects economy [16, 35, 36, 79], the running pace may have been awkward for the girls from a biomechanical perspective. No biomechanical data other than stride frequency were collected, however. Another limitation to this study was the small number of higher BMI girls who participated. If more of the higher BMI girls had participated in the study, better comparisons could have been made between the high and normal BMI groups.

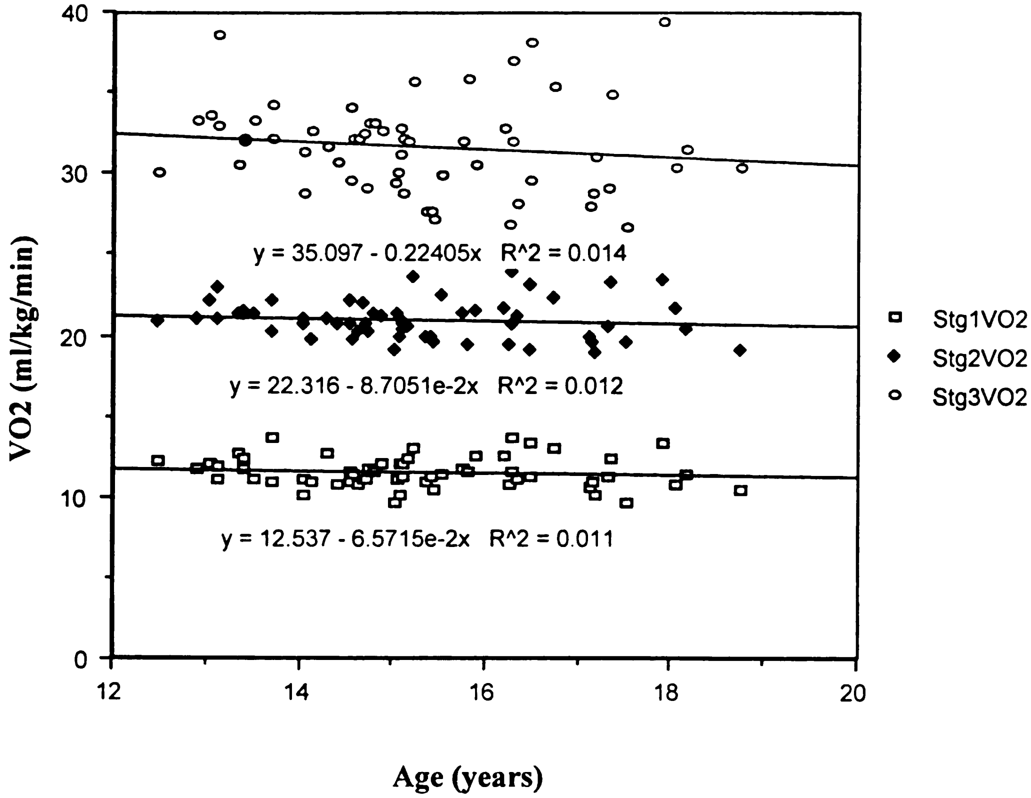
In summary, results of this study indicated that there was no relationship between age and economy in adolescent girls matched for height and weight. HR was a predictor of economy during all three treadmill phases. The only other factors that appeared to relate to economy were V_E, body surface area, and stride frequency in the third stage of the treadmill test. However, these other factors did not play a large role in predicting economy. Results of our previous economy study indicated that size played a role in economy differences between adolescent girls and adults, but there might be other factors involved. Results of this study did not clarify what other physiological or biomechanical factors may be related to economy. More research is needed on what role walking and/or running speed may play in treadmill economy.

Figure 3.1. Relationship between age and VO2max



NOTE: VO2max (K) represents data from Krahenbuhl et al., 1985

Figure 3.2. Relationship between age and economy in stages 1, 2, and 3



CHAPTER FOUR

RATING OF PERCEIVED EXERTION IN ADOLESCENT GIRLS

ABSTRACT

The test-retest reliability and validity of the Borg and OMNI rating of perceived exertion (RPE) scales were examined in a population of adolescent girls (N=58, age=15.3±1.5 years). Participants were randomly assigned to which scale they used, as well as which treadmill exercise condition (walking, walking uphill, or jogging). Results of intraclass correlation (ANOVA) indicated that the OMNI scale (R=0.95) was more reliable than the Borg scale (R=0.78). Single-day reliability estimates were slightly lower with OMNI (r=0.91) more reliable than the Borg scale (r=0.64). Standard error of measurement for the Borg scale was 1.24 scale units, while standard error of measurement for the OMNI scale was 0.49 scale units. Criterion validity was determined using Pearson Product Moment correlation analysis, with % HR_{max} and $\%VO_{2max}$ as the criterion measures. Validity estimates were higher for the OMNI scale compared to the BORG. Specifically, validity coefficients (r) were 0.86 and 0.89 for the OMNI, compared to 0.66 and 0.70 for the Borg, for $\%HR_{max}$ and $\%VO_{2max}$ comparisons, respectively. Although the OMNI scale has not been tested in adolescent girls, it appears to be more reliable and valid than the Borg scale for use in this population during treadmill exercise.

INTRODUCTION

Perceived exertion has been defined as the ability to detect and respond to sensations that arise as a result of physiological adaptations to exercise [57]. The cognitive awareness of these sensations is considered to be a form of biofeedback in which central, peripheral, and metabolic changes during exercise are assimilated. Borg designed the first rating of perceived exertion (RPE) scale and believes RPE to be the best indicator of degree of physical strain [13].

Borg's 6-20 RPE instrument is a category scale that was designed to increase linearly with exercise intensity for work on a cycle ergometer [13]. There are also verbal descriptions associated with odd numbered responses (see Appendix A). For example, a Borg RPE value of 7 corresponds to "very, very light", while number 19 corresponds to "very, very hard". The scale was originally devised for use with adult males, and each number value on the scale is meant to correspond to heart rates (HR) ranging from 60-200 $b \cdot min^{-1}$ (e.g., an RPE score of 14 would correspond to an HR of 140 $b \cdot min^{-1}$). Many researchers and practitioners use the RPE scale on a regular basis [13], but Borg himself admitted that "there may not be one perfect scale for all kinds of subjective intensities in all kinds of situations" [13].

The use of RPE in the pediatric population has not been well-studied [40], and it is not clear whether or not the original Borg scale is appropriate for use with children. Children ages 8-12 years reported a wide RPE range for a given treadmill intensity in one study [46]. In fact, Robertson and Noble [61] indicated there might be an age threshold associated with use of the Borg scale. Lamb et al. [41] questioned the use of Borg's RPE scale in young adult males, but other researchers have found it to be reliable in children and adolescents [46, 47, 61, 86]. Further, Bar-Or and Ward found that obese adolescents reported higher RPE for a given workload than non-obese. However, the obese participants were working at a higher percentage of their aerobic capacities [10].

The Children's OMNI Scale of Perceived Exertion was developed specifically for use with children of mixed race and sex [60]. This scale uses numerical ratings that range from 0-10 and a series of pictures showing a child on a bicycle (see Appendix C). The zero end of the scale is represented by flat ground, and the rest of the exercise levels are depicted with the child riding the bicycle uphill. Validation work has been done on the OMNI scale, and results have shown it is valid over a range of exercise intensities [60]. However, it is not clear that the OMNI has been validated against higher-end exercise intensity, and all validation performed so far has used cycle ergometer exercise in 8-12 year old children. The authors noted they do not know if the scale is generalizable to other exercise modes or children or adolescents of different ages. Thus, the OMNI scale appears to have promise for use with children and adolescents but has not been well-studied.

Since RPE is an indicator of physical strain, it may be a factor in physical activity behavior. However, this issue has not been addressed in the literature. One reason for not addressing a potential relationship between RPE and physical activity is contradictory evidence presented thus far regarding the appropriateness of the various scales that are available. It is not clear which RPE scales are most reliable and valid for use with this population. The purpose of this study was to compare the reliability and validity of the Borg and OMNI RPE scales during submaximal treadmill exercise in a population of adolescent girls ages 13-18.

METHODS

Participants. Study participants were adolescent females, ages 13-18. Participants were excluded if they were trained runners (i.e., ran more than 10 miles per week), but were not excluded if they participated in other physical activities or team sports. Written assent to participate and parental consent was obtained for each participant. This research was approved by the University Committee on Research Involving Human Subjects (UCRIHS) at Michigan State University.

Instruments. Two different RPE scales were used in the testing protocol. Prior to performing the exercise tests, participants were familiarized with each scale.

Borg 6-20 RPE (category) scale. The Borg category scale [13] is designed to describe subjective perceptions of exercise (physical stress). The scale consists of numbered choices, 6-20, and verbal cues, from "very, very light" to "very, very hard". During the last minute of each phase of the testing protocol, participants were asked how hard they felt they were exercising. All instructions given to participants followed the guidelines outlined by Bar-Or [8].

Children's OMNI scale of perceived exertion. The OMNI scale was developed specifically for use with children of mixed race and sex status. The OMNI is an 11-point scale, consisting of numbered choices, 0-10, and verbal cues, from "not tired at all" to "very, very tired". The scale also has a set of four pictures of a boy riding a bicycle. The first picture is placed at the level zero and depicts the boy riding on flat ground. The other three pictures show the boy riding uphill, with the boy appearing more and more tired as the scale progresses. These other three pictures are positioned between the 2-4, 5-7, and 8-10 on the scale. Participants were asked how they feel according to this scale during each minute of the last phase of the exercise test.

Testing protocols. Data were collected on two occasions, approximately one week apart. The testing protocols involved treadmill exercise, with the first day including habituation and the second day including a test with three different exercise stages. During both treadmill bouts, expired gases were collected continuously via indirect calorimetry (SensorMedics 2900; Yorba Linda, CA). Heart rate was measured via telemetry (Polar; Seattle, WA) and recorded for each minute of exercise. Prior to data collection, participants were randomly assigned to use one of the RPE scales for one of the three exercise stages. Random assignment involved creating a list of all possible combinations of RPE scale and treadmill stage. Each combination was assigned a number, and a random number table was used to choose the number of the combination each participant would use.

The protocol for the habituation session on the first day lasted 10-15 minutes. Participants always began the habituation day by walking 2.0 mph, followed by 3.0 mph at 5.0% grade, followed by jogging at 4.5 mph. Each girl spent six minutes in the randomly assigned stage and two to five minutes in each of the other two stages. After the sixth minute HR value for the assigned stage was recorded, participants were asked to rate their perceived exertion level according to the appropriate RPE scale (Borg or OMNI, whichever they were assigned).

The protocol for the second treadmill testing session involved sitting quietly for 10 minutes followed by three, six-minute, steady-state exercise stages. The three exercise stages corresponded to the same intensities previously mentioned for the habituation day. Participants were asked their RPE during the last 30 seconds of the same stage at which they were asked RPE during the habituation test.

Statistical analysis. Reliability was determined using intraclass correlations (ANOVA). Single test reliability was determined using the Spearman-Brown prophecy formula: $r = K * (r_1) / [1 + (K-1) * r_1]$ where K is the number of trials performed and r_1 is the reliability coefficient established for K trials. Standard errors of measurement (SEM) were calculated using the formula: SEM = SD * SQRT(1-r) where SD is the standard deviation of the RPE scores, and r is the intraclass correlation coefficient. Validity was determined using Pearson correlation, with both percent of HR maximum ($\%HR_{max}$) and percentage of aerobic capacity ($\%VO_{2max}$) as criterion measures.

RESULTS

Borg RPE scores differed by approximately one point between the two days. OMNI RPE scores did not differ by more than half a point between the two days. RPE scales are presented in Table 4.1. Intraclass correlation (via repeated measures ANOVA) was used to determine reliability for each scale. The OMNI scale showed better reliability (R=0.95) than the Borg scale (R=0.78). Single-day reliability estimates (which represent an estimate of the reliability if the scale was given at only one point in time) were slightly lower with OMNI (r=0.91) being more reliable than the Borg scale (r=0.64). Standard error of measurement for the Borg scale was 1.24, while standard error of measurement for the OMNI scale was 0.49.

Table 4.1 RPE values for days one and two

	Day One			Day Two		
	Mean	*St. Dev.*	*Median*	*Mean*	*St. Dev.*	*Median*
Borg Stage 1 (n=9)	8.2	2.2	7.0	8.0	1.7	8.0
Borg Stage 2 (n=9)	11.1	1.8	11.0	12.0	1.7	12.0
Borg Stage 3 (n=10)	11.5	2.3	12.0	12.7	2.1	13.0
OMNI Stage 1 (n=10)	0.3	0.5	0.0	0.7	0.8	0.5
OMNI Stage 2 (n=10)	2.3	1.3	2.0	2.4	1.0	2.0
OMNI Stage 3 (n=9)	4.8	1.6	5.0	5.2	1.6	5.0

Criterion validity was determined using Pearson Product Moment correlation analysis, with % HR_{max} and %VO_{2max} as the criterion measures (see Table 4.2 for %HR_{max} and %VO_{2max} data). Validity estimates (r) were higher for the OMNI scale compared to the BORG. Specifically, validity coefficients were 0.86 and 0.89 for the OMNI, compared to 0.66 and 0.70 for the Borg, for %HR_{max} and %VO_{2max} comparisons, respectively.

Table 4.2 RPE level and %HR_{max} and %VO_{2max} by exercise stage

Stage	*%HR_{max}* Mean	*St. Dev.*	*%VO_{2max}* Mean	*St. Dev.*
Borg Stage 1	53.3	2.8	24.2	2.5
Borg Stage 2	70.8	7.1	47.5	5.8
Borg Stage 3	82.6	5.0	65.8	4.7
OMNI Stage 1	51.2	4.9	23.1	2.3
OMNI Stage 2	64.0	6.7	44.0	4.9
OMNI Stage 3	87.9	6.8	73.4	12.8

DISCUSSION

The reliability estimate for the Borg scale in this study is similar to those found in other studies. Mahon and Marsh[46] reported the same reliability estimate for the Borg scale in children ages 8-12 at ventilatory threshold as was found in the present investigation. In adolescent, obese children Bar-Or and Ward found an average RPE reliability of R=0.92 across different exercise intensities[10]. They also found coefficients of R=0.59 at 20% of aerobic capacity and R=0.89 at 80% of aerobic capacity in another group of obese adolescents.

The reliability estimate for the OMNI scale in this study was excellent. We were unable to compare our estimate to previous estimates because no other data are presently available regarding the reliability of the OMNI scale. Thus far, the creators of the scale have only reported validity but not test-retest reliability. There was less than 0.5 point difference between both days of OMNI RPE estimates for all three treadmill stages. Also, the SEM was low for the OMNI scale, indicating that a measurement error of approximately half a point affects the true RPE value.

Traditionally, a common criterion used to validate RPE scales has been HR at a given workload[7, 20, 27]. However, in this study validity was determined by using both %HRmax and $\%VO_{2max}$ as criterion measures. We considered these to be the best criterion measures because a) the participants' actual HR_{max} and VO_{2max} values were known and b) these max values differed among the subjects.

In studies where HR was used as a criterion measure for RPE, Borg scale validity coefficients have been good to excellent. Gillach et al. [27] found validity coefficients between Borg scale RPE and HR of r=0.92 and r=0.94 in 11-14 year-old participants on two different occasions. In contrast, Eston et al. [22] found a somewhat lower validity coefficient between Borg scale RPE and HR of r=0.74 in a study with adolescent boys. Correlations between Borg scale RPE and HR fell anywhere between 0.70 and 0.88 for individuals ages 7-20 years in Bar-Or's studies[7]. All previously mentioned studies were performed using cycle ergometer.

Correlations between Borg scale RPE and $\%HR_{max}$ and $\%VO_{2max}$ in the present investigation were r=0.66 and r=0.70. The values for $\%HR_{max}$ are slightly lower than those reported for previous studies, but two of the previously mentioned investigations correlated RPE score directly with HR rather than $\%HR_{max}$[22, 27]. Bar-Or appears to be the only investigator who has examined RPE related to $\%HR_{max}$. He plotted the data rather than calculating the correlation coefficient, however. Based on the plots, the RPE-

$\%HR_{max}$ relationship displayed by his participants appears similar to the participants in the current investigation for the first two treadmill stages. During the third treadmill stage, our participants reported lower RPE values at a higher $\%HR_{max}$ than Bar-Or's participants. It is unknown why this phenomenon occurred. However, our participants were fitter than average girls their age [67], and it is possible that they reported lower RPE scores than less fit individuals might report. The fitness level of Bar-Or's participants is unknown. However, his participants were all males.

When the original validation of the OMNI scale was performed, Robertson et al.[60] used both HR and VO_2 as criterion measures. The authors employed regression analysis to determine if there was a linear relationship between OMNI RPE and both HR and VO_2. The model for HR had r=0.93, and the model for VO_2 had an r=0.94. The scale was developed for, and validated on children ages 8-12 during cycle ergometer exercise. To our knowledge, the present investigation is the first to examine the validity of the OMNI scale for use with adolescents during treadmill exercise. Results showed that validity estimates were higher than those found with the Borg scale, regardless of whether $\%HR_{max}$ (r=0.86) or $\%VO_{2max}$ (r=0.89) were used as criterion measures. These values are similar to those found in the original validation study of the OMNI scale.

Each participant used one RPE scale during one stage of the treadmill testing. It is unknown how the reliability and validity coefficients may have been affected by this protocol. Most other studies examining reliability and validity of RPE scales have included assessment of RPE at several stages of exercise. This could be viewed as either a limitation or a strength of this study. It could be a limitation because individual participants did not assess RPE at different intensities. It could be viewed as a strength if one assumes that RPE assessment in one stage did not affect subsequent ratings. We considered both points while designing the study. Since our purpose was to determine reliability and validity of the scales, we decided it was best to use RPE at one given stage, rather than allow earlier assessment to affect later ones.

Another potential limitation of this study was the method by which reliability was determined. The conditions for assessing RPE were not exactly the same on the first and second days. All first-day assessments of RPE were measured during a six-minute treadmill stage that was one of the three treadmill stages completed on the second day. Despite the fact that participants did perform the other two stages on the first day, the stages were not performed for the full six-minute time period that they were on the second day. Our idea was to assess RPE for one given stage so that any RPE measurement would not be affected by previous measurements, and we believe we achieved this.

Overall, our results indicate that the OMNI scale is a reliable and valid instrument to use with adolescent girls performing treadmill exercise. The results are particularly interesting to note because our study is the first to include OMNI reliability data on an adolescent population during treadmill exercise. Although the OMNI scale was originally developed for use with 8-12 year-olds performing cycle ergometer exercise, we found it to be more reliable and valid than the Borg scale for treadmill exercise in adolescent girls. Recommendations for further research include testing the OMNI scale with younger age participants and examining its reliability and validity using other exercise modalities.

CHAPTER FIVE

RELATIONSHIP BETWEEN ECONOMY, RATING OF PERCEIVED EXERTION, AND PHYSICAL ACTIVITY

Physical inactivity is a major cardiovascular disease risk factor for adults. It has been found to have an inverse association with coronary heart disease incidence and morbidity and mortality of several chronic diseases [59]. Although cardiovascular disease risk factors often do not manifest until adulthood, investigators have begun to focus attention on physical activity during childhood. Researchers are currently searching for determinants of physical activity during childhood and adolescence with the hope that active children will become active adults. Unfortunately, current evidence shows that physical activity declines during adolescence, especially in females [48]. Although there is only moderate evidence that physical activity tracks (i.e., remains stable) from childhood to adulthood [49], researchers generally agree that it is important for children to become and stay physically active [6]. The Surgeon General's Report on Physical Activity and Health indicates that children should participate in regular physical activity, and continue to do so throughout their lives [76].

A search of existing literature uncovered no evidence that any researchers have examined either exercise economy or rating of perceived exertion (RPE) as potential determinants of physical activity [72]. It is conceivable that an adolescent who has poor walking and running economy feels he/she cannot adequately perform and is subsequently discouraged from participating in physical activities involving this skill. It is also possible that an individual who perceives a physical task to be intense may be deterred from participating in the activity. Without a theory to test or any data available regarding potential relationships, it is difficult to determine what those relationships might be. The purpose of the fourth study hypothesis was to examine potential relationships between economy, RPE, and physical activity (see Figure 5.1 for a model).

METHODS

Each study participant visited the Human Energy Research Laboratory on two occasions. Participants were asked to recall physical activities from the previous day using the Previous Day Physical Activity Recall (PDPAR; see Appendix H) which has been validated in children and adolescents [84]. Completing the PDPAR involves identifying the duration and intensity of physical activity behaviors for the entire day and recording the values in the corresponding boxes on the activity recall form. The first page of the recall includes pictorial and verbal clues regarding how to identify physical activity intensity. The four physical activity intensity choices range from "very light: slow breathing, little or no movement" to "hard: hard breathing, moving quickly". The original plan was to schedule testing days to provide PDPAR assessments that would represent two different types of day (i.e., weekday and weekend), but due to scheduling difficulties this rarely occurred. Participants completed the PDPAR during the beginning of each laboratory visit.

Study participants also answered questions from the Youth Risk Behavior Surveillance Survey [34] (see Appendix I). The Centers for Disease Control (CDC) developed the survey to focus attention on important health problems in youth. After reviewing leading causes of morbidity and mortality, representatives from the CDC decided the survey should cover six areas: behaviors that resulted in unintentional and intentional injuries, tobacco use, alcohol and other drug use, sexual behaviors, dietary behaviors, and physical activity [34]. A steering committee was appointed by the CDC to choose questions that would address prevalence of behaviors in the six main areas. The total number of questions needed to be limited so that students would be able to complete the questionnaire in a 45-minute class period. Eight questions pertain to physical activity, which the participants in this study answered during their first visit to the laboratory.

Data analysis. The PDPAR data were collected as minutes spent in activity. These data were averaged across both days and placed into five different categories: Total PDPAR minutes, very light activity minutes, light activity minutes, medium activity minutes, and hard activity minutes. The YRBSS questions were all structured using number of days, number of minutes, or number of sports teams. A lower numbered response to a YRBSS question means less days, minutes, or sports teams, depending on the question.

YRBSS questions 1, 4, 6, 7, and 8 were considered the most relevant to physical activity behaviors, as well as the most likely to have relationships to both economy and RPE. Question 1 asks the number of days in the last week the girls participated in activities that made them sweat and breathe hard for 20 minutes or more (an attempt to measure vigorous physical activity). Question 4 asks the number of days in the last week the girls walked or bicycled for at least 30 minutes (an attempt to measure moderate physical activity). Question 6 asks how many minutes the girls are active in an average physical education class. Questions 7 and 8 ask about sport team participation. To determine potential relationships, a correlation matrix was run between economy, RPE, and physical activity (see Appendix G).

RESULTS AND DISCUSSION

The correlation matrix between economy, RPE, and physical activity appears in Appendix G. A negative correlation would be expected for the relationship between economy and physical activity, assuming that a more economical person would be more physically active (have more PDPAR minutes and more days, minutes, or sports teams on the YRBSS). A negative correlation would also be expected for the relationship between RPE and physical activity, assuming that someone who perceives an activity as less intense would be more physically active. A positive correlation would be expected for the relationship between economy and RPE, assuming that a more economical person (i.e., lower oxygen consumption) would perceive an activity as less intense.

Relationship between economy and physical activity. It is possible that economy could affect physical activity behavior, or that physical activity behavior could affect economy. Although the expected direction of correlations between economy and physical activity is negative, most of our relationships between PDPAR scores and economy were positive. None were significant (Appendix G).

Questions from the YRBSS that are most likely to show a good picture of physical activity are numbers 1, 4, 6, and 7/8. Participants in this sample were more vigorously (question 1) and moderately (question 4) physically active and played on more sports teams (questions 7 and 8) than both the national and state averages (see Table 5.1). Fewer participants in this sample participated in 20 minutes or more of physical activity during physical education class (question 6) than the national or state averages. However, only 39% of this sample did <u>not</u> take physical education classes, compared to 48% of the national and 72% of the Michigan samples.

The highest (negative) correlations between economy and YRBSS questions were significant and occurred for treadmill stage 3, although questions number 1, 2, 3, and 7 correlated well with economy in all three treadmill stages. Question 1, which asks on how many of the last 7 days the girls performed vigorous activity, correlated best for all treadmill economy stages (r= -0.4, r= -0.5, r= -0.5 for stages 1, 2, and 3, respectively, $P<0.05$). Question 7, which asks on how many school sports teams the girls participated, displayed the next best correlation coefficients (r= -0.4 for both stage 2 and stage 3, $P<0.05$). These results indicate that the more economical girls spent the most time being physically active in the week prior to data collection and participated on the most school sports teams. Whether good economy makes one more likely to be active (including sports), or whether being active and playing sports improves one's economy cannot be discerned from these data.

Table 5.1. Prevalence of behaviors in YRBSS questions

	Current sample (%)	Nationwide average (%)	Statewide average (%)
Question 1	77	57	57
Question 4	71	16	21
Question 6	52	70	80
Question 7	90	48	53

NOTE: Data for questions 1, 6, and 7 is from Kann et al., 2000 [32]
Data for question 4 is from Kann et al., 1998 [31]

When examining the relationship between exercise economy and physical activity, one must consider that the PDPAR scores did not correlate well with the YRBSS scores. It seems reasonable to expect fairly high, positive correlations between the PDPAR minutes and YRBSS answers, assuming that the girls who reported the most activity minutes were active on most days (or minutes) and participated on the highest number of school-sponsored sports teams. However, the correlations between the

PDPAR and YRBSS were mostly negative and ranged from ~r= -0.2 to 0.2. A possible reason for this apparent lack of correlation is the fitness level of the study participants. Participants would often classify events such as soccer games as "medium" or even "light". It is likely that some activities the girls performed might be classified as more intense by girls who were less fit. In fact, it is possible that some physical activities were not considered as such and thus, were not reported on the PDPAR, despite prompting from the investigator. In contrast, the YRBSS questions asked specifically about activities in which participants "breathed hard" and "sweat", and perhaps were a more valid measure of physical activity in our sample.

It is possible that the PDPAR was not a good instrument to use with this population. It is also possible that there is no relationship between economy and physical activity. However, the increase in the correlation coefficient between treadmill economy and YRBS Question 1 with increasing exercise intensity suggests that perhaps these two variables are related. If a more objective monitoring device had been used to assess physical activity, different results may have been found. It is also possible that the large (and typical) standard deviations found in PDPAR scores masked a true relationship. Further, if the treadmill speed (particularly in stage 3) truly was inefficient for several of the girls in the sample (as the data indicate), then a better relationship between economy and physical activity might be found at a slightly faster pace.

Relationship between RPE and physical activity. It is difficult to infer much from the correlation coefficients between RPE and physical activity. There were only 9-10 participants for each RPE-treadmill stage combination. Nevertheless, there were a few significant correlation coefficients between RPE and the PDPAR minutes. Borg RPE for stages 1 and 2 correlated moderately (r= -0.5 and r= -0.4, $P<0.05$) with number of very light activity minutes and number of light activity minutes, respectively. OMNI RPE for stage 1 correlated moderately with total PDPAR minutes (r= -0.5, $P<0.05$). OMNI RPE for stages 2 and 3 correlated moderately (r= -0.4, $P<0.05$) with number of minutes spent in light activity.

There were many significant ($P<0.05$) correlation coefficients in the expected direction for RPE versus the YRBSS questions. The first YRBSS question correlated moderately (r= -0.5) with OMNI RPE for the second stage. The fourth YRBSS question correlated moderately with Borg RPE for stage 2 (r= -0.6). The sixth YRBSS question correlated moderately (r= -0.4) with OMNI RPE for stage 1 and well (r= -0.7) with OMNI RPE in stage 3. The seventh YRBSS question correlated moderately (r= -0.4) with Borg RPE in stage 2 and OMNI RPE in stage 3.

Given the exploratory nature of this study, it is difficult to state exactly what these correlations mean in terms of a true impact of a girl's RPE on her on physical activity behavior. Since the first two treadmill stages were of low and moderate intensity, one might expect a good relationship between RPE during these stages and very light, light, and medium minutes on the PDPAR. However, there was only a moderate relationship between Borg RPE for stage 1 and very light activity minutes, and Borg RPE for stage 2 and light activity minutes. It is interesting to note that OMNI RPE for stage 1 had a moderate relationship with overall PDPAR activity minutes. Thus, there is some evidence that a relationship exists between RPE and physical activity, but the topic warrants further investigation with a more focused design and more study participants.

Relationship between economy and RPE. Out of six possible correlations, only three were in the expected (positive) direction. Only one of these three was significant ($P<0.05$), which was OMNI RPE during stage 3 ($r=0.7$). This represents an interesting finding, as the girls who were less economical during jogging reported higher RPEs. The small number of participants (n=9) included in this correlation is a limitation, but this topic also warrants further investigation with more participants.

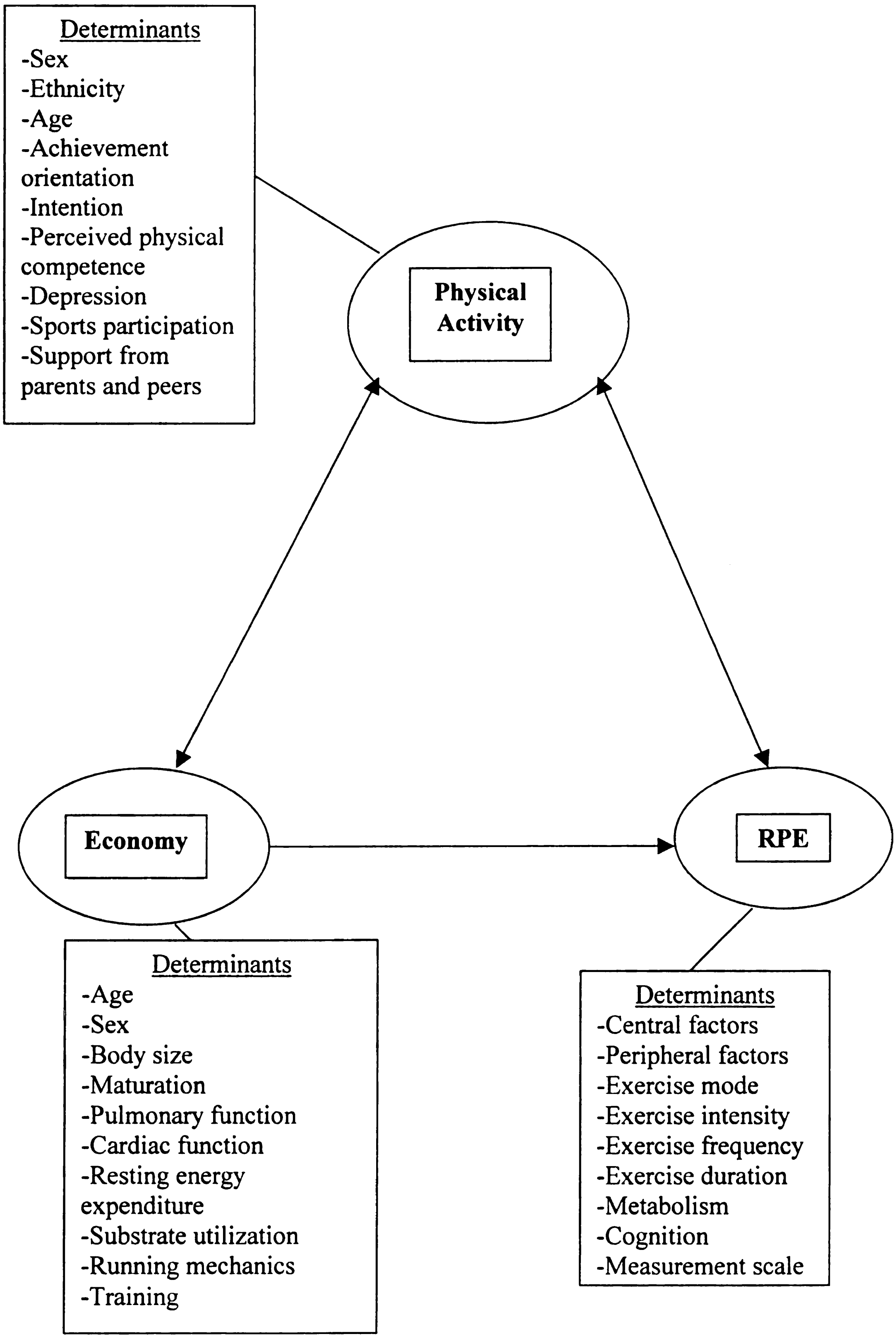
There is good potential for further investigation into these relationships. Economy should be examined over a wider range of treadmill speeds. Physical activity should be measured objectively with motion-detecting devices such as a pedometer or the Computer Science and Applications (CSA) accelerometer. Use of a portable metabolic analyzer to assess economy in a field setting may also provide a better correlation between economy and physical activity, since most life activities do not occur while an individual walks and jogs on a treadmill or rides a cycle ergometer. Also, sampling designs must better insure that participants represent the intended population. Although it is difficult to find girls who are less fit and/or active to participate in exercise studies, their data are important to consider. This is important from a public health perspective since it is the less fit/active girls who are most in need of physical activity.

There are also methods to consider that may help better examine those relationships between RPE and economy. A large sample would allow collection of several data points for an RPE assessment at a given stage. This way, one RPE measurement would not affect subsequent measurements, but sufficient data would be available to make valid comparisons. RPE could also be assessed in combination with measures obtained from portable metabolic analyzers and objective physical activity measures. RPE should be assessed during activities in field settings to determine if traditional laboratory testing has provided accurate and generalizable data. Developmental psychologists may need to be consulted in order to determine how children learn to perceive exertion. Despite creation of child-specific scales, the idea that children can detect and report perceived exertion in the same way as adults is still applied in all research to date.

The best method for examining all these relationships is to conduct longitudinal studies. Longitudinal studies would provide the best assessment of how variables change over time. They would also help researchers understand if improvements in one's economy of movement or physical activity behaviors can be made.

In summary, it appears that the concepts of exercise economy and RPE as determinants of physical activity may be warranted as topics for future investigations. Physical activity is a multi-faceted behavior that is affected by many factors. Factors affecting one individual may not affect another. If physical education instructors can improve children's motor skill performance at young ages, they may help to improve children's economy. Although the correlations found in this study do not imply causality, it is possible that improvement in exercise economy may affect RPE and/or physical activity behavior. Without longitudinal research spanning from childhood through adolescence, it is difficult to project which factors are the most important in convincing children to lead healthy lifestyles as adults.

Figure 5.1 Proposed model for relationships among economy, RPE, and physical activity



Appendix A

Appendix A

Borg's RPE Scale

6-

7- Very, very light

8-

9- Very light

10-

11- Fairly light

12-

13- Somewhat hard

14-

15- Hard

16-

17- Very hard

18-

19- Very, very hard

20-

Appendix B

Appendix B

Children's Effort Rating Table (CERT)

1……Very, very easy

2……Very easy

3……Easy

4……Just feeling a strain

5……Starting to get hard

6……Getting quite hard

7……Hard

8……Very hard

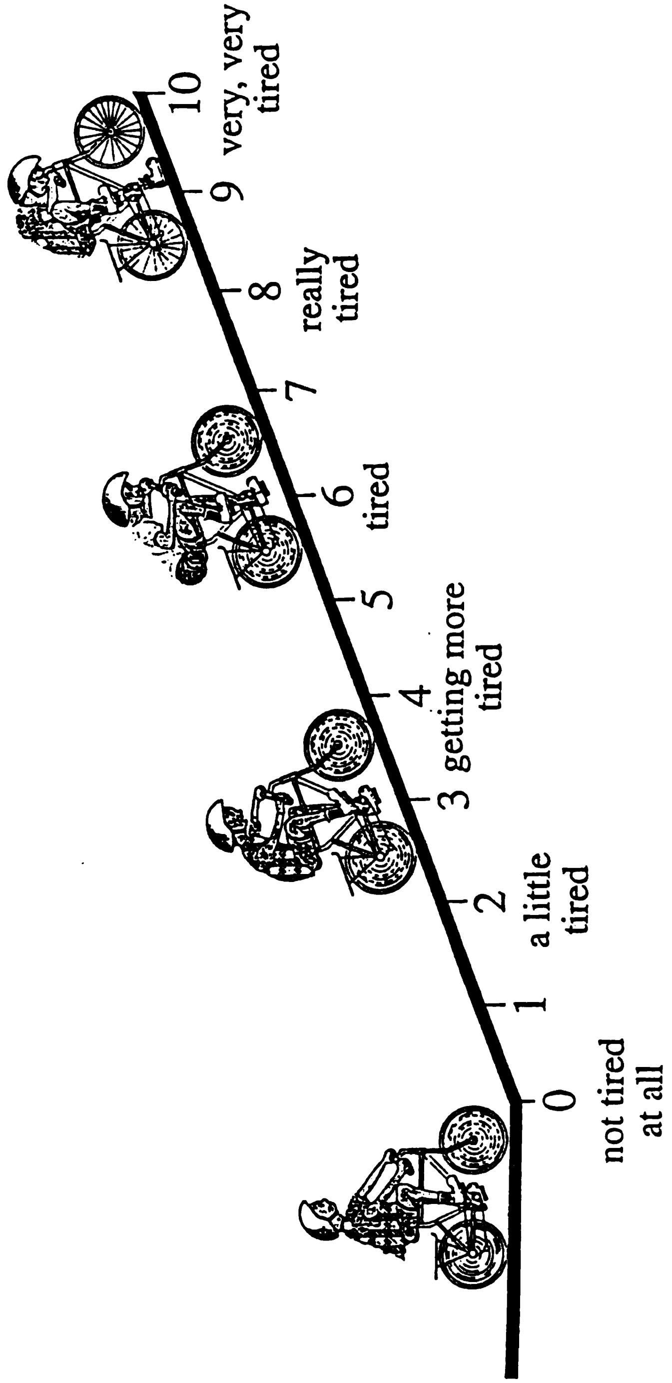
9……Very, very hard

10…..So hard I am going to stop

Appendix C

Appendix C

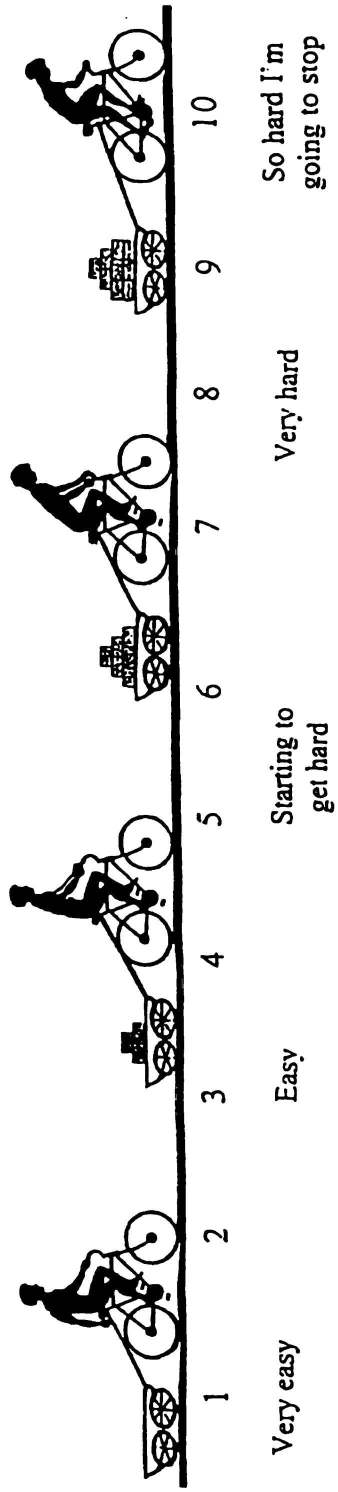
Children's OMNI Scale of Perceived Exertion



Appendix D

Appendix D

Cart and Load Effort Rating (CALER) Scale



Appendix E

Appendix E

Consent Form

Title: Running economy in adolescent females

I, ______________________, the parent / guardian of ______________________ grant permission to enroll my child in a study to examine the variables which affect running economy. The entire amount of time required per participant is about two hours total.

As children grow, the amount of energy required to do certain types of exercise (e.g., walking, jogging) changes. The reasons for this remain unclear. The purpose of this study is to examine these changes between adolescents of different ages.

On both test days, the participant's height and weight will be measured prior to any testing that takes place. On the first day, the participant will undergo pulmonary function testing. This testing involves breathing into a device called a spirometer, which will measure lung volume. A new, separate mouthpiece is used for each child. In addition, each participant will answer questions pertaining to physical activity behavior, physical activity self-efficacy, and background, including date of onset of menstruation and menstrual history. These questions will be asked by a female investigator. Finally, each child will have a practice session on the treadmill to become familiar with treadmill walking and running. The practice session will last 10-15 minutes, or until she is comfortable on the treadmill. She will also wear a heart rate transmitter belt around her chest in order to familiarize her with use of the instrument.

On the second test day, each participant's sitting height, shoulder and hip breadth, and skinfold thicknesses of her calf, arm, hip, thigh, and back will be measured (by a female investigator). She will again be asked to answer questions about her physical activity behavior. In addition, she will perform an exercise test. The exercise test will involve walking and jogging on a motorized treadmill. Prior to the test, the participant will sit for 10 minutes while seated in a chair on top of the treadmill. The treadmill test itself will begin with a six minute warm-up at 2 mph, 0.0% grade. Next, she will walk at 3.0 mph, 5.0% grade for six minutes. Then she will jog at 4.5 mph, 0.0% grade for six minutes. After 18 minutes of walking and jogging, the grade will increase 2.5% each minute until she can no longer keep up. Then the test will be stopped when the participant indicates that she wishes to stop.

During the treadmill test, breath will by analyzed to determine the amount of oxygen each participant uses during the test. This will involve her inhaling room air through a mouthpiece and exhaling expired air into the same mouthpiece, which will be connected to a hose that will channel the air into a machine for analysis. Also, she will be wearing an elastic chest strap that will measure her heart rate during the test.

I understand that there are possible risks in the study. However, they are very minimal. No one can <u>absolutely</u> guarantee that any person, no matter how fit, or how young, will not suffer a heart attack or related problem during the test. The risk of this in a population with KNOWN heart disease is less than 1 in 100,000 hours of testing. It is likely that the risk is much less in healthy adolescents. All researchers involved with the testing have been trained in cardiopulmonary resuscitation (CPR).

If the participant has any medical condition (e.g., asthma, orthopedic problems, heart condition, etc.) which might be a reason not to exercise, the investigators should be informed prior to any testing.

A record of each child's participation in the study will be kept in a confidential file at Michigan State University. Each participant's privacy will be protected to the maximum extent allowable by law. She is free to withdraw from the study at any time and for any reason. Such withdrawal will not jeopardize her future treatment. There will be no cost for participating in this study and each participant will receive a movie pass and $10.00 at the end of the test to defer the cost of transportation.

If one is injured as a result of participation in this research project, Michigan State University will provide emergency care if necessary. If the injury is not caused by the negligence of MSU, you are personally responsible for the expense of this emergency care and any other medical expenses incurred as a result of this injury. My signature below, and my child's signature, acknowledges her voluntary participation in this research project. Such participation does not release the investigators, institutions, sponsor, or granting agency from their professional and ethical responsibility to my child.

If there are any questions regarding this research project, including those regarding participants' rights as human subject, feel free to contact any of the following individuals: Karin Allor, M.S., Project Coordinator 355-4734; James Pivarnik, Ph.D., Project Supervisor 353-3520; David Wright, Ph.D., Chair of University Committee on Research Involving Human Subjects 355-2180.

I have read this consent form and received answers in those areas which were not clear. I am willing to give consent for my child to participate in this study.

Study Participant Signature	Date
	Phone Number
Address	
Parent/Guardian Signature	Date
Investigator Signature	Date

Appendix F

Appendix F

Approval form from University Committee on Research Involving Human Subjects

MICHIGAN STATE
UNIVERSITY

October 26, 2000

TO: James PIVARNIK
3 I.M. Sports Circle

RE: **IRB# 00-607** CATEGORY:2-D
APPROVAL DATE: October 19, 2000

TITLE: RUNNING ECONOMY IN ADOLESCENT FEMALES

The University Committee on Research Involving Human Subjects' (UCRIHS) review of this project is complete and I am pleased to advise that the rights and welfare of the human subjects appear to be adequately protected and methods to obtain informed consent are appropriate. Therefore, the **UCRIHS approved this project.**

RENEWALS: UCRIHS approval is valid for one calendar year, beginning with the approval date shown above. Projects continuing beyond one year must be renewed with the green renewal form. A maximum of four such expedited renewals possible. Investigators wishing to continue a project beyond that time need to submit it again for a complete review.
REVISIONS: UCRIHS must review any changes in procedures involving human subjects, prior to initiation of the change. If this is done at the time of renewal, please use the green renewal form. To revise an approved protocol at any other time during the year, send your written request to the UCRIHS Chair, requesting revised approval and referencing the project's IRB# and title. Include in your request a description of the change and any revised instruments, consent forms or advertisements that are applicable.
PROBLEMS/CHANGES: Should either of the following arise during the course of the work, notify UCRIHS promptly: 1) problems (unexpected side effects, complaints, etc.) involving human subjects or 2) changes in the research environment or new information indicating greater risk to the human subjects than existed when the protocol was previously reviewed and approved.

If we can be of further assistance, please contact us at 517 355-2180 or via email: UCRIHS@msu.edu. Please note that all UCRIHS forms are located on the web: http://www.msu.edu/user/ucrihs

Sincerely,

Ashir Kumar, MD
Interim Chair, UCRIHS

AK: br
cc: Karin Allor
3 I.M. Sports Circle

OFFICE OF
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Appendix G

Appendix G

Correlation Matrices

Table G.1. Correlation matrix for potential factors affecting economy in the first treadmill stage

	Age	Menar.	BMI	St1 VO2	VO2 max	Bi-acrom.	Biiliac	Sum Fold	Stride Freq.	Sit height	BSA	VO2/ BSA	VO2/ stride	HR
Age	1													
Menar.	.014	1												
BMI	.249	-.249	1											
St1VO2	-.104	.200	-.300	1										
VO2max	-.203	.08	-.367	.200	1									
Biacrom.	.232	.12	.555	-.200	-.053	1								
Biiliac	-.016	.115	.216	-.100	-.168	.314	1							
Sumfold	-.124	-.096	.607	.081	-.464	.236	.317	1						
Stride freq.	.100	.036	-.200	.005	.100	-.200	-.300	-.300	1					
Sitheight	.096	-.181	-.003	-.003	.128	.159	.343	.018	-.075	1				
BSA	.157	-.158	.653	-.200	-.177	.534	.412	.478	-.269	.493	1			
VO2/BSA	.100	.100	.300	.794	-.003	.200	.200	.500	-.200	.100	.300	1		
VO2/stride	-.100	.107	-.100	.800	.100	-.100	.200	.200	-.500	-.129	-.033	.822	1	
HR	-.021	.200	-.103	.500	-.400	-.154	.200	.300	-.023	-.034	-.085	.400	.400	1
VE	.109	-.016	.300	.400	-.100	.100	.100	.500	-041	.300	.500	.600	.300	.300
FVC	.035	.048	.23	-.002	.283	.354	.225	.149	-.200	.606	.598	-.021	-.113	-.200
MVV	.249	-.109	.005	-.02	.377	.113	-.077	-.18	-.117	.478	.299	-.024	.035	-.19

NOTE: Menar.= age at menarche, Biacrom= biacromial breadth, Biiliac= biiliac breadth, Sumfold = sum of five skinfolds, Sitheight= sitting height, BSA= body surface area, VO2/BSA= oxygen consumption per unit body surface area, VO2/stride= oxygen consumption per stride

Table G.2. Correlation matrix for potential factors affecting economy in the second treadmill stage

	Age	Menar.	BMI	St2 VO2	VO2 max	Bi-acrom.	Biiliac	Sum Fold	Stride Freq.	Sit height	BSA	VO2/ BSA	VO2/ stride	HR
Age	1													
Menar.	.014	1												
BMI	.249	-.229	1											
St2VO2	-.100	.200	-.100	1										
VO2max	-.203	.08	-.367	-.049	1									
Biacrom.	.232	.12	.555	-.135	-.053	1								
Biiliac	-.016	.115	.216	-.22	-.168	.314	1							
Sumfold	-.124	-.096	.607	.081	-.464	.236	.317	1						
Stride freq.	.100	.100	-.100	.001	.028	-.200	-.400	-.200	1					
Sitheight	.096	-.181	-.003	-.229	.128	.159	.343	.018	-.200	1				
BSA	.157	-.158	.653	-.20	-.177	.534	.412	.478	-.269	.493	1			
VO2/BSA	.100	.006	.500	.700	-.300	.400	.200	.400	-.200	-.100	.300	1		
VO2/stride	-.100	.100	.100	.800	-.100	.100	.200	.100	-.500	-.100	-.019	.500	1	
HR	.041	.200	.100	.600	-.500	-.154	.100	.300	-.100	-.300	-.100	.400	.500	1
VE	.100	-.107	.600	.400	-.00	.123	.200	.500	-.100	.100	.400	.500	.300	.600
FVC	.035	.048	.23	-.100	.283	.354	.225	.149	-.200	.606	.591	.200	.100	-.300
MVV	.249	-.109	.005	-.02	.377	.113	-.077	-.18	-.117	.478	.299	-.024	.035	-.19

NOTE: Menar.= age at menarche, Biacrom= biacromial breadth, Biiliac= biiliac breadth, Sumfold = sum of five skinfolds, Sitheight= sitting height, BSA= body surface area, VO2/BSA= oxygen consumption per unit body surface area, VO2/stride= oxygen consumption per stride

Table G.3. Correlation matrix for potential factors affecting economy in the third treadmill stage

	Age	Menar.	BMI	St3 VO2	VO2 max	Bi-acrom.	Biiliac	Sum Fold	Stride Freq.	Sit height	BSA	VO2/ BSA	VO2/ stride	HR
Age	1													
Menar.	.014	1												
BMI	.249	-.229	1											
St3VO2	-.115	.005	-.093	1										
VO2max	-.203	.08	-.367	-.144	1									
Biacrom.	.232	.12	.555	-.135	-.053	1								
Biiliac	-.016	.115	.216	-.22	-.168	.314	1							
Sumfold	-.124	-.096	.607	.081	-.464	.236	.317	1						
Stride freq.	.093	.258	-.279	-.476	.119	-.16	-.158	-.344	1					
Sitheight	.096	-.181	-.003	-.229	.128	.159	.343	.018	-.075	1				
BSA	.157	-.158	.653	-.20	-.177	.534	.412	.478	-.269	.493	1			
VO2/BSA	-.024	-.113	.472	.794	-.328	.229	-.006	.464	-.568	-.152	.243	1		
VO2/stride	-.125	-.107	.062	.919	-.152	-.028	-.082	.219	-.776	-.129	-.018	.822	1	
HR	-.021	-.015	.058	.741	-.488	-.154	-.01	.289	-.39	-.289	-.085	.643	.69	1
VE	.109	-.107	.41	.647	-.479	.123	-.004	.466	-.46	-.037	.32	.738	.66	.585
FVC	.035	.048	.23	-.208	.283	.354	.225	.149	-.076	.606	.591	-.021	-.113	-.282
MVV	.249	-.109	.005	-.02	.377	.113	-.077	-.18	-.117	.478	.299	-.024	.035	-.19

NOTE: Menar.= age at menarche, Biacrom= biacromial breadth, Biiliac= biiliac breadth, Sumfold = sum of five skinfolds, Sitheight= sitting height, BSA= body surface area, VO2/BSA= oxygen consumption per unit body surface area, VO2/stride= oxygen consumption per stride

Table G.4 Correlation matrix for relationship of economy, RPE, and physical activity

	Stg1 VO2	Stg2 VO2	Stg3 VO2	Borg 1	Borg 2	Borg 3	OMNI 1	OMNI 2	OMNI 3	PDPAR avg	VLavg	Lavg	Mavg	Havg
YRBS1	-.4	-.5	-.5	-.3	-.2	<.1	.2	-.5	<.1	-.3	-.1	<-.1	-.2	-.2
YRBS2	-.2	-.3	-.3	-.5	-.1	-.3	.3	-.8	.4	-.4	-.2	<-.1	-.2	-.3
YRBS3	-.3	-.3	-.3	.1	-.5	.4	.4	-.3	-.1	-.3	-.1	-.1	-.1	-.2
YRBS4	-.1	-.1	.1	-.2	-.6	.5	.3	-.1	.1	-.1	.2	-.1	-.2	-.2
YRBS5	-.1	-.2	-.2	.2	.5	.3	-.4	.3	-.3	.2	.2	<.1	<.1	.1
YRBS6	.1	-.1	-.1	.3	-.3	.7	-.4	-.1	-.7	.1	.1	<-.1	<.1	.2
YRBS7	-.2	-.4	-.4	-.1	-.4	.2	-.3	-.3	-.4	-.1	-.1	.1	.1	-.3
YRBS8	.1	<.1	.1	-.1	-.2	-.2	-.1	-.1	-.3	-.1	<.1	-.2	-.2	<.1
PDPARavg	.3	.3	.2	.1	.3	-.1	-.5	.6	-.1					
VLavg	-.1	-.1	<.1	-.5	-.2	<.1	.1	-.2	.4					
Lavg	.2	.2	<.1	-.1	-.4	.2	-.3	-.4	-.4					
Mavg	.1	.2	<.1	-.2	.3	-.2	-.2	.2	<.1					
Havg	.2	.3	.3	.4	.3	<-.1	-.3	.7	-.1					
Stg1VO2				-.1			.3							
Stg2VO2					.3			-.2						
Stg3VO2						-.2			.7					

NOTE: Stg1VO2-Stg3VO2 are economy in stages 1, 2, and 3; Borg 1-3 and OMNI 1-3 are RPE-stage values; PDPARavg = average minutes of physical activity on the PDPAR, VLavg-Havg = average minutes of very light, light, medium, and hard physical activity on the PDPAR

Appendix H

Appendix H

Previous Day Physical Activity Recall (PDPAR)

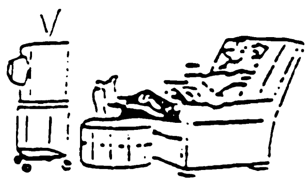
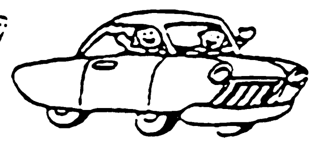
Activities Scale

On the next page is a scale which records the main activities you did yesterday. Please be sure to write on the scale what day yesterday was.

1. For each time period write in the number(s) of the main activities you did in the boxes on the time scale.
2. Then try to remember how HARD you felt like you were working and how LONG you did the activity. Write how LONG you did the activity in the box that corresponds to how HARD you felt like you were working in the boxes on the time scale.

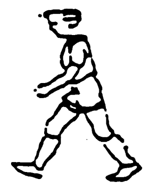
- Very Light- Slow breathing, little or no movement.



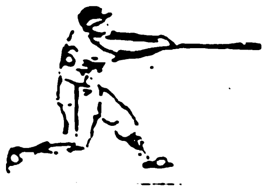



- Light- Normal breathing, regular movement.

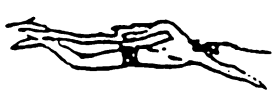
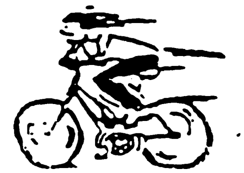



- Medium- Increased breathing, moving quickly


- Hard- Hard breathing, moving quickly.


Please be as accurate as possible.

Activity Numbers

Eating
1. Meal
2. Snack
3. Cooking

Sleep/Bathing
4. Sleeping
5. Resting
6. Shower/bath

Transportation
7. Ride in car/bus
8. Travel by walking
9. Travel by bike

Work/School
10. Job (list)
11. Homework
12. Household chores (list)

Spare Time
13. Watch TV/Play video games
14. Go to movies/concert
15. Listen to music
16. Talk on phone
17. Hang around
18. Shopping
19. Hobby (list)
20. Other (list)

Physical Activities
21. Bicycle (easy pace)
22. Walk (slowly)
23. Dance (for fun)
24. Swim (for fun)
25. Skateboard
26. Play organized sport (slow pace)
27. Play individual sport (slow pace)
28. Bicycle (fast)
29. Walk (fast)
30. Jog/run
31. Swim laps
32. Lift weights
33. Aerobic dance
34. Play organized sport (fast pace)
35. Individual exercise (fast pace

Previous Day Physical Activity Recall

1. Put activity numbers in this column ⇓

2. Write how long you did the activity in the box corresponding to how hard the activities were ⇓

Time	Activity Number	Very Light	Light	Medium	Hard
7:00					
7:30					
8:00					
8:30					
9:00					
9:30					
10:00					
10:30					
11:00					
11:30					
12:00					
12:30					
1:00					
1:30					
2:00					
2:30					
3:00					
3:30					
4:00					
4:30					
5:00					
5:30					
6:00					
6:30					
7:00					
7:30					
8:00					
8:30					
9:00					
9:30					
10:00					
10:30					

Write the day of the week you did these activities ______________

Appendix I

Appendix I

Youth Risk Behavior Surveillance System Questions

1. On how many of the past 7 days did you exercise or participate in sports activities for at least 20 minutes that made you sweat and breathe hard, such as basketball, jogging, fast dancing, swimming laps, tennis, fast bicycling, or similar aerobic activities?

a. 0 days	e. 4 days
b. 1 day	f. 5 days
c. 2 days	g. 6 days
d. 3 days	h. 7 days

2. On how many of the past 7 days did you do stretching exercise, such as toe touching, knee bending, or leg stretching?

a. 0 days	e. 4 days
b. 1 day	f. 5 days
c. 2 days	g. 6 days
d. 3 days	h. 7 days

3. On how many of the past 7 days did you do exercises to strengthen or tone your muscles, such as push-ups, sit-ups, or weight lifting?

a. 0 days	e. 4 days
b. 1 day	f. 5 days
c. 2 days	g. 6 days
d. 3 days	h. 7 days

4. On how many of the past 7 days did you walk or bicycle for at least 30 minutes at a time (including walking or bicycling to or from school)?

a. 0 days	e. 4 days
b. 1 day	f. 5 days
c. 2 days	g. 6 days
d. 3 days	h. 7 days

5. In an average week when you are in school, on how many days do you go to physical education (PE) classes?

a. 0 days	c. 2 days	e. 4 days
b. 1 day	d. 3 days	f. 5 days

6. During an average physical education (PE) class, how many minutes do you spend actually exercising or playing sports?
   a. I do not take PE
   b. Less than 10 minutes
   c. 10 to 20 minutes
   d. 21 to 30 minutes
   e. More than 30 minutes

7. During the past 12 months, on how many sports teams run by your school did you play? (Do not include PE classes)
   a. 0 teams
   b. 1 team
   c. 2 teams
   d. 3 or more teams

8. During the past 12 months, on how many sports teams run by organizations outside your school did you play?
   a. 0 teams
   b. 1 team
   c. 2 teams
   d. 3 or more teams

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