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THE MEASUREMENT OF PHYSICAL ACTIVITY IN CHILDREN

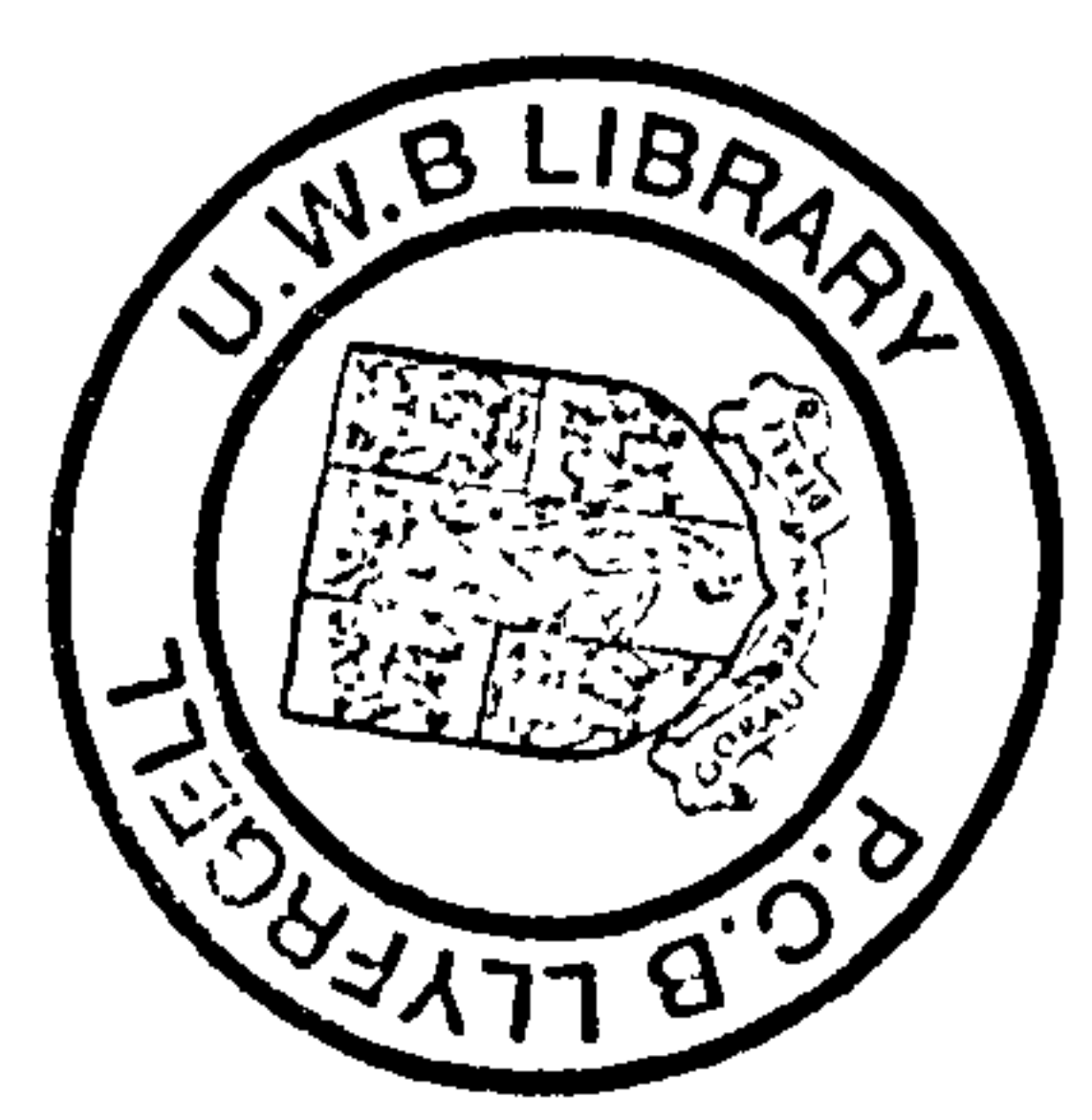
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Thesis submitted for the Degree of Doctor of Philosophy of the
University of Wales

School of Sport, Health and Physical Education Sciences,
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Winter, 1998

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I would also like to extend a special thank you to my family, for their endless patience and support.

SUMMARY

This thesis includes one qualitative literature review, three empirical studies and one meta-analysis examining the measurement of physical activity in children. Previous research has highlighted the difficulties inherent in measuring children's habitual activity. This has led to confusion regarding the relationships between physical activity and health in children. Recently a new type of activity monitor has been developed. Uniaxial (WAM, Computer Science Applications, Shalimar, Florida, USA) and triaxial (Tritrac, Professional Products, a division of Reining International, Madison, WI, USA) accelerometers that record temporal, frequency and intensity information of movement are now commercially available. The aims of this thesis were to evaluate the validity of these and other measures of physical activity in children, to examine the relationship between physical activity and body fat in children and to investigate the effect the mode of activity measurement has on this relationship.

The main findings were: a) The Tritrac provided a significantly better estimate of scaled oxygen consumption during typical children's activities than the WAM, heart rate or pedometry; b) Physical activity, measured by the Tritrac or the pedometer, was inversely correlated with body fat and positively correlated with aerobic fitness; c) Heart rate measures of physical activity did not correlate significantly with body fat or aerobic fitness; d) Meta-analytic procedures showed a small to moderate relationship between activity levels and body fat in children; e) The strength of this relationship was heavily dependent on the method used to assess activity levels. Observation methods produced an effect size significantly higher than questionnaire or heart rate methods, though not significantly different to motion counter methods. In conclusion it appears that heart rate methods are inappropriate for the assessment of habitual activity in children. The use of motion counters or observation methods for assessing activity are recommended. Motion counter methods are particularly appropriate for medium to large sample sizes.

CHAPTER 1

INTRODUCTION

Background

Children are the most physically active sector of the population (Rowland, 1998). However, recently there has been increasing concern over their physical activity levels. This follows several studies purporting to show children's activity levels to be shockingly low (Armstrong et al., 1990; Gilbey and Gilbey, 1995). This concern over health and activity in children has led to the development of policy frameworks aiming to increase the opportunities for participation in physical activity available to young people (Health Education Authority, 1998).

Levels of habitual physical activity decline dramatically as children grow older (Verschuur and Kemper, 1985; Saris et al., 1986). A decrease in physical activity with age is natural. It has been shown in other animals with no access to the sedentary trappings of television, computers, cars etc. unique to the human race (Goodrich, 1974). However, indirect evidence indicates that activity levels have dropped considerably over the last decade. Despite a decrease in the total number of calories consumed the prevalence of obesity has doubled (Prentice and Jebb, 1995).

It is, perhaps, inevitable that the increase in labour saving devices in the home and workplace, motorised transport and sedentary recreational

activities would lead to a decrease in physical activity. In modern society, participation in physical activity is a personal choice and relies on a person's desire to be active. However, the genetic constitution of human beings has changed little since the stone age (Vigilant et al., 1991; Wilson and Cann, 1992). Physiologically we are not suited to this sedentary lifestyle, hence the increased prevalence of chronic diseases, such as coronary heart disease and obesity (Blair et al., 1996).

Children, too, are now faced with choosing whether or not to be active. The increasing choices of sedentary past-times (e.g. television, videos and computer games) are often more attractive than active alternatives. Coupled with this are decreasing opportunities to be active. Parents are worried about allowing children outside to play due to fears of abduction and road accidents. The same worries often lead to children being transported to and from school (Dixey, 1998).

The risks of an inactive lifestyle on the health of adults are well established. Sedentary living increases the risk of developing coronary heart disease, obesity, osteoporosis, hypertension and atherosclerosis (Bouchard et al., 1994). Being physically active might also contribute to mental health; the incidence of depression is lower in habitually active people (Brown, 1990; McAuley, 1994).

In children the relationship between physical activity and health is less clear. Risk factors for coronary artery disease have been found in children as young as three years old (Saris, 1986; Sallis et al., 1988). However, it is not known whether the presence or absence of risk factors are related to children's activity levels. There are several possible reasons for

this: a relationship between activity levels and health may only be present in the adult; current methods of measuring activity in children may not be sensitive enough to assess the typical spontaneous bursts of activity typical in childhood; or activity levels in childhood may have a delayed effect and not be apparent until adult life (Blair et al., 1989a).

It has been argued that physical activity should be promoted in childhood even if there is little evidence for a positive effect on the cardiovascular health of children (Gutin and Owens, 1996). This is partly based on the assumption that an active child is more likely to be active in adult life, where the health-physical activity links have been proved. There is limited evidence for the tracking of physical activity from childhood to adulthood (Activity and Health Research, 1992). However, methodological difficulties may decrease the chances of identifying a link. Studies have relied on adults recall of how active they were as children and on childhood participation in sports teams/clubs (Dishman & Dunn, 1988), and therefore have not used objective methods to assess childhood activity patterns. This method is confounded by problems relating to children's limited ability to recall activities (Sallis, 1991). This is naturally compounded when adults attempt to remember their childhood activities. Additionally, in longitudinal studies, the emotional and cognitive development of the child would be a confounding variable, affecting the accuracy of recall of physical activities.

The majority of young children enjoy physical activity and look forward to PE lessons at school (Fox, 1994). Targeting children in an effort to enhance their present activity levels in a way that is likely to encourage continued participation in physical activity may be more effective than

targeting adults, who are often disillusioned with activity (Fox, 1991). Encouraging activity in childhood may lead to a maintenance of activity levels during adult life and/or prevent the early occurrence of risk factors. Cardiovascular disease risk factors have been shown to track in children (Orchard et al., 1983). Potentially, regular physical activity throughout childhood may prevent this tracking of risk factors, though this has not been demonstrated (Sallis, 1987). If this does occur, encouraging physical activity during childhood becomes even more important. However, it is not currently known if there is any value in targeting these groups due to the little evidence for tracking of physical activity levels.

If an active childhood can delay or prevent chronic diseases, either directly or by increasing the likelihood of activity during adult life, quality of life could be improved and chronic health care costs may decrease. This is particularly important as the average lifespan is increasing with an increased ageing population (Spiriduso, 1995, pp. 8-11). Together with the increase in sedentary lifestyles this could lead to large increases in the number of people needing hospital and nursing care, hence enormous health costs, just at a time when there are fewer young people to pay for them.

Whether or not there are health benefits related to childhood physical activity, and whether or not these benefits come in childhood or adulthood, remains elusive without valid and objective methods for assessing children's physical activity. Similarly, the degree of tracking of physical activity from childhood to adulthood cannot be determined without an objective method for the measurement of activity levels throughout childhood and adulthood.

The primary focus of this thesis was to test the validity of current and new methods of assessing typical childhood physical activity. The rationale for this research was the commercial availability of a new type of monitor for the assessment of physical activity. This new generation of activity monitor supersedes all previous motion sensors, and has made it possible to record temporal, frequency and intensity characteristics of movement more accurately. Both uniaxial (WAM, Computer Science and Applications Inc., Shalimar, Florida) and triaxial (Tritrac-R3D, Professional Products, a division of Reining International, Madison, WI, USA) accelerometers are available.

Once a valid method for assessing physical activity in children had been established the aim was to use this method to assess relationships between physical activity and fatness in children. The particular aspects of physical activity that affect fatness were of interest. For example, does activity have to be at a given intensity before benefits are obtained, or is total activity important regardless of how it is made up?

Structure of the Thesis

This thesis is structured as five papers: one qualitative literature review; two laboratory-based empirical studies; one field-based empirical study; and one quantitative literature review (meta-analysis). Each paper focuses on issues relating to the measurement of physical activity in childhood. Measuring physical activity levels, particularly in children, has always been

problematic. Hence, the conflict in the literature over the relationship between children's activity levels and their health.

The first paper was a qualitative literature review (Chapter 2) to provide a critical overview of the advantages and disadvantages of the various methodologies used to assess physical activity in children. This highlighted the often inadequate validation of methodologies, particularly regarding assessment of children's activity.

The first and second empirical studies (Chapters 3 and 4) were therefore designed to assess the validity of several tools (heart rate, pedometry, uniaxial accelerometry and triaxial accelerometry) for measuring physical activity across two ethnically diverse populations. Steady state oxygen uptake was used as the criterion measure of energy expenditure for a variety of typical children's activities: walking; running; playing catch; playing hopscotch; and sitting and crayoning. For all activities, oxygen uptake was scaled for body mass. Identical protocols were followed for both the investigations, the first with a sample of British schoolchildren and the second with a sample of Hong Kong Chinese schoolchildren. To ensure that the protocol in both studies was identical the author of this thesis travelled to Hong Kong to help design the study and supervise initial pilot testing. The raw data was returned to the author for analysis.

Once the validity of the instruments had been established the next phase of the thesis was to move out of the laboratory environment and assess children's habitual physical activity in the field. The third investigation examined the relationships between physical activity and body fat and aerobic fitness in children (Chapter 5). Physical activity was

measured using three types of monitors (heart rate monitors, pedometers and accelerometers). This allowed the examination of the effect of mode of activity measure on the above relationships.

The fourth study, a meta-analysis, was designed to place the third study in the context of previous research (Chapter 6). There is a wealth of literature concerned with fatness-activity relationships in children. This study aimed to quantitatively summarise the available literature, to facilitate the comparison of effect sizes elicited by the various distinct methods of assessing physical activity. The intent was to show if the method of measuring physical activity affected the observed relationship between activity and fatness.

The literature review and studies in this thesis have formed the basis of discrete scientific papers which have been accepted for publication in peer-reviewed journals, except for the meta-analysis which is under review. The published paper resulting from each study is indicated at the foot of each respective title page. The author of this thesis produced the first draft of each paper, except for the Hong Kong study (Chapter 4), and was responsible for all re-drafting of all papers.

Chapter 7 (Conclusions) summarises the findings and implications of the above research. Additionally it examines the potential of the activity monitors for use in diverse areas of health research, e.g. bone mineral health, tracking of physical activity, coronary heart disease rehabilitation.

CHAPTER 2

LITERATURE REVIEW

¹The Measurement of Physical Activity in Children with Particular Reference to the use of Heart Rate and Pedometry

¹ This study formed the basis of a critical review paper published in Sports Medicine: Rowlands, A.V., Eston, R.G. & Ingledew, D.K. (1997). The measurement of physical activity in children with particular reference to the use of heart rate and pedometry. *Sports Medicine*, 24, 258-272.

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CHAPTER 3

STUDY 1

²Validity of Heart Rate, Pedometry and Accelerometry for Predicting the Energy Cost of Children's Activities

² This study formed the basis of an empirical study published in the *Journal of Applied Physiology*: Eston, R.G., Rowlands, A.V. & Ingledew, D.K. (1998). Validity of heart rate, pedometry and accelerometry for predicting the energy cost of children's activities. *Journal of Applied Physiology*, 84, 362-371.

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CHAPTER 4

STUDY 2

³Validity of heart rate, pedometry, and accelerometry for estimating the energy cost of activity in Hong Kong Chinese boys.

³ This study formed the basis of an empirical study accepted for publication in *Pediatric Exercise Science*: Louie, L., Eston, R.G., Rowlands, A.V., Tong, K.K., Ingledew, D.K. & Fu, F.H. (In press). Validity of heart rate, pedometry and accelerometry for estimating the energy cost of activity in Hong Kong Chinese boys. *Pediatric Exercise Science*.

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CHAPTER 5

STUDY 3

⁴The Relationship Between Activity Levels, Aerobic Fitness, and Body Fat in 8-10 year old Children

⁴ This study formed the basis of an empirical study accepted for publication in the *Journal of Applied Physiology*: Rowlands, A.V, Eston, R.G. & Ingledew, D.K. (In press). The relationship between activity levels, aerobic fitness and body fat in 8-10 year old children. *Journal of Applied Physiology*.

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CHAPTER 6

STUDY 4

⁵The relationship between body fatness and habitual physical activity in children: A meta-analysis

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CHAPTER 7

CONCLUSIONS

Main findings

This thesis has shown that it is desirable to measure movement directly when assessing children's physical activity levels. Evidence for this was indicated in two controlled laboratory studies, a field study and a meta-analysis. Results indicate that the use of heart rate to assess children's activity levels may not be appropriate and is less valid than more direct measures of movement.

This thesis contains the first study (Chapter 3) to assess the validity of activity measures over a range of typical children's activities, against the criterion of oxygen consumption. The Tritrac, WAM, heart rate and pedometer activity measures correlated highly with scaled oxygen consumption, during a variety of treadmill and unregulated play activities in British 8 to 10 year old children. The vector magnitude from the Tritrac assessed activity significantly better than the WAM, pedometer and heart rate measures. Surprisingly, pedometer was no different from heart rate at assessing all activities and was significantly better at assessing play activities alone. Repeating the study with 8 to 10 year old Hong Kong Chinese boys (Chapter 4) elicited very similar results. This showed that all the activity monitors tested were valid across two distinct ethnic groups.

The next empirical study (Chapter 5) related habitual daily activity levels, assessed by Tritrac, pedometer and heart rate, to body fat and aerobic

fitness levels in 8 to 10 year old British children. Body fat correlated negatively with total, moderate and vigorous activity measured by the Tritrac; and with total activity measured by the pedometer. Conversely, in girls, the amount of time spent with the heart rate exceeding 139 bpm (a common measure of physical activity used in the literature) correlated positively with body fat. This could be taken to indicate that the fatter the girl the more active she was. Although mean net heart rate did have a negative correlation with body fat ($r = -0.11$), this was not significant and was substantially lower than the correlations of the activity monitors with body fat ($r = -0.42$). The relationships between treadmill endurance time (a measure of aerobic fitness) and physical activity also differed, depending on whether activity monitors or heart rate measures were used to assess activity levels. All output measures from the Tritrac and the pedometer correlated positively with aerobic fitness. Correlations with heart rate measures were not significant and were substantially lower than when pedometry or Tritrac activity measures were used.

The magnitude of the correlations between activity and body fat, or activity and aerobic fitness were similar, irrespective of whether the Tritrac or the pedometer was used to measure activity. This finding is extremely encouraging and has important implications for large-scale studies. Simple pedometry is relatively inexpensive and can provide accurate physical activity information, both in children and adults. For the analysis of changes in the daily pattern of activity the Tritrac is the ideal monitor, but for measuring total activity the pedometer is ideal. The field study showed that total activity was at least as important as moderate/vigorous activity in the

relationship between body fat levels and aerobic fitness in 8-10 year old children. This supports current recommendations for children's activity levels (Health Education Authority, 1998).

The final study used meta-analytic procedures to determine the relationship between fat and activity. The analysis included all previous studies, meeting certain standardised entry criteria, that could be located. This study also indicated that heart rate measures were limited and could even be considered inappropriate tools for measuring children's activity levels. The percentage of heart rate studies showing the expected inverse relationship was 25%, compared with 78% across all activity measures. Behavioural measures of activity, namely observation and motion counters, identified the strongest relationships with body fatness. However, when cumulating all studies regardless of activity measure, there was still a small to moderate significant relationship between fat and activity (95% confidence interval $r = -0.12$ to -0.20).

The results from the meta-analysis indicate that movement counters and observation measures captured those aspects of physical activity which are important for controlling levels of body fat and aerobic fitness. Individual differences complicate heart rate measures of physical activity. Although, some of these differences can be controlled for, e.g. taking into account the resting heart rate, some differences, such as increases in heart rate for non-activity reasons are more difficult to control for. Perhaps behavioural measures are more capable of accounting for the spontaneous short lasting activity typical of children than are physiological measures.

Methodological issues

Statistical conclusion validity

This refers to the validity of conclusions, or inferences, based on statistical tests of significance. Cook and Campbell (1979, p. 39) listed three decisions about covariation to be made with the sample data when evaluating any experiment. These were: (1) is the study sensitive enough to permit reasonable statements about covariation?; (2) if it is sensitive enough, is there any reasonable evidence from which to infer that the presumed cause and effect covary?; (3) if there is such evidence, how strongly do the two variables covary? The first question can be answered by calculating the statistical power of the study. This refers to the power the study has of detecting a given effect size with the variances and sample sizes on hand.

Studies 1 and 2

In the controlled laboratory tests it was hypothesised that a large effect size would be elicited for the relationships between the activity measures and scaled oxygen consumption. Previous research has shown correlations greater than 0.70 between heart rate and oxygen consumption, and accelerometry and oxygen consumption in adults (Bouten et al., 1994; Luke et al., 1997; Melanson and Freedson, 1995). Cohen (1992) defines a large effect size as 0.5. This is lower than the expected effect size so leaves a margin for detecting effect sizes considerably lower than expected. The sample size necessary to detect this effect size with a power of 80% and an

alpha of 0.05 is 28 (Cohen, 1992). The actual sample size was 30 for the UK study, and 21 for the Hong Kong study. However, seven repeated measures were made on each subject, one for each different activity. Hence, the effective N in the UK study ranged from 159 - 177 and in the Hong Kong study ranged from 143 - 147 (variability in N was due to listwise deletion for missing data). The implications of repeated measures regression are discussed in Appendix B2. Correction for the use of repeated measures rather than independent data points did not change the significance of the results. Considering the large N 's involved the power of both these studies was considerably greater than 80%.

Studies 3 and 4

The literature suggests that if a relationship exists between the level of body fat or aerobic fitness and physical activity in children it would be small to moderate. Cohen (1992) defines a small effect size as $r = -0.10$ and a moderate effect size as $r = -0.30$. To detect a medium effect size with a power of 80% and an alpha of 0.05 requires a sample size of 85. To detect a small effect size requires a sample size of 783. Due to time and equipment restraints the sample size in the study was only 34. Hence, the study was not powerful enough to detect the effects sizes the literature would lead us to expect. This increases the risk of Type II error; failure to detect an effect that is present. However, the effect sizes elicited in study 3 were larger than expected (indicating moderate to large relationships) and hence elicited significant relationships.

Due to the low power of this study the aim was to include it in a later meta-analysis of similar studies (Study 4, Chapter 6). The study alone may not be powerful enough to detect significant relationships, but combined with other studies a powerful analysis would be possible. If all studies conducted are required to have sufficient statistical power, the sample sizes required may prevent many studies being conducted. However, very precise meta-analysis results can be obtained by combining studies which alone have inadequate statistical power (Schmidt, 1996). The need for impossibly large sample sizes is not a barrier to addressing a given research question if cumulation of studies is the aim.

Internal validity

This refers to the validity with which statements can be made about whether there is a causal relationship from one variable to another in the form in which variables were manipulated or measured.

Studies 1 and 2

The children were familiar with all activities with the exception of walking and running on the treadmill. Hence, treadmill walking and running was the only new skill the children were required to learn. To prevent the learning of the skill affecting the results, the children underwent a familiarisation period on the treadmill prior to testing.

The children varied in their habituation to the mouthpiece. Lack of familiarity with a mouthpiece can cause hyperventilation, particularly in sedentary activities. To prevent this from affecting the results, each child was familiarised with the mouthpiece for a few minutes prior to data collection. Additionally expired air was collected throughout each activity, but only steady state readings were used. Therefore each child was habituated to each different activity with the mouthpiece before readings were taken. The most sedentary activity was last to ensure that the children were relatively comfortable with the mouthpiece and the laboratory environment when resting measures were required. Resting heart rate was checked to ensure the children had adequate rest before the sedentary activity.

Ideally the activities should have been presented in a random order to eliminate any effects due to order of activity. Unfortunately, this was not possible. The treadmill activities were presented first and were in a sequential order: walking and then running. This was to eliminate the need for rest periods during the treadmill activities. The children were permitted to be out of school for a certain period of time and hence resting between every activity was not possible due to the imposed time constraints. The next two activities (hopscotch and catch) were presented randomly. Crayoning, the most sedentary activity, was always last for reasons described above.

The criterion measure used in these studies was scaled oxygen consumption. This was a major strength in the internal validity of these studies. Frequently, activity measures are validated against criterion

measures that are used to infer oxygen consumption or energy expenditure. For example, heart rate is commonly used, but the relationship between heart rate and oxygen consumption is influenced by the muscle groups used, the type of activity undertaken, temperature, and individual differences (Riddoch and Boreham, 1995). Doubly labelled water can be used to provide an accurate measure of total energy expenditure over an extended period of time, but it cannot be used for short term activities as used in these studies.

Study 3

As this was a field-based study it was impossible to control all possible variables. The nature of the study necessitated relying on the child and parent to report the times the pouch containing the monitors was worn. However, the Tritrac output provided confirmation of the times reported. Each monitor was stored in tightly stitched pockets within the pouch to ensure no extraneous movement. Hence, all movement counts registered were due to actual movement of the subject and not to movement of the monitors inside the pouch. The receiver for the heart rate monitor was also stored in the pouch, rather than worn on the wrist to prevent the children pressing any buttons. The pouch was locked to prevent tampering with any of the monitors.

There was no attempt to control for other variables that may affect the relationship between activity and fatness.

External validity

This refers to the generalisability of the study to the population which the sample is supposed to represent.

The empirical studies in this thesis considered one age group only; 8 to 10 year old children. It is recognised that this limits the generalisability of the results, where older and younger children are concerned. Validation studies are necessarily labour intensive and hence it would not have been possible to sample sufficient children to cover a wider age range. It was felt that the avoidance of age as a confounding variable by restricting the ages of subjects included was more practical.

As in the majority of studies which require active participation all subjects were volunteers. It was not possible to obtain a random sample. However, the mean height and body mass of children in all samples were within normal values for their respective populations (Tanner & Whitehouse, 1984; Fu, 1994).

Studies 1 and 2

In the British study both boys and girls participated, hence the results are generalisable across gender. However, in the Hong Kong study only boys were used. The repetition of the study with Hong Kong Chinese boys elicited very similar results to the study with British boys and girls. This shows that the results are generalisable across two distinct ethnic groups. External validity was enhanced by including activities which were

considered to be representative of the type of movements children make during normal behaviour. This is contrary to other similar studies which restrict activities to treadmill walking and/or running (e.g. Maliszewski et al., 1991; Melanson and Freedson, 1995). As children's habitual activity cannot be reproduced in the laboratory, we felt this was the closest we could get to validating the monitors for a variety of activities against a valid criterion.

For the UK study only one Tritrac accelerometer and one WAM accelerometer were used for all subjects. The use of only one of each type of accelerometer limits the generalisability to other units. This was also true of the accelerometers used in the Hong Kong study. Tritrac results for the UK and Hong Kong studies were very similar, indicating inter-unit reliability. However, in the UK study the WAM counts appeared to jam at a high level for some activities. This did not occur with the WAM accelerometer in the Hong Kong study, so it is possible one of the WAM accelerometers had a fault. The overall conclusions regarding the accuracy of the monitors were the same for both the Hong Kong and UK study, so if one of the WAM accelerometers was faulty this did not have any effect on the conclusion of the study.

Study 3

In this study the subjects were aware that they would have various health-related fitness measures, including a measure of body fat and be required to exercise to maximal volitional exertion. Hence, it is possible that the

volunteers were leaner and fitter than the general population. However, descriptive data of body composition, height and body mass did not differ from norms for the general population. The fitness test revealed that boys had average fitness and the girls had below average fitness. It therefore appears that, regarding fatness and fitness the sample was fairly representative of the general population of boys and girls the same age.

Both genders were studied, allowing results to be calculated separately for boys and girls. However, fatness and activity, and aerobic fitness and activity relationships did not differ by gender. Hence, generalisation was not restricted to one gender.

Time restrictions meant children's activity levels were measured during one period in the year only. Some studies have found children's activity levels to differ by season (Crocker et al., 1997), which infers that ideally the children should be measured at least once during each season. Weekend and weekday activity were measured for each child. This was important as children's activity levels are generally lower during the weekend than during the week (Armstrong et al., 1991).

The children were encouraged not to change their behaviour in any way while wearing the pouches. The measurement of activity levels was designed to have minimal intrusion into normal activities and no attempt was made to assess the relationship between diet and physical activity or diet and body fat levels. We felt that any requirement to fill in a diary regarding diet or activity levels would have been more likely to affect the children's normal behaviour than just wearing a lightweight pouch. The literature has highlighted problems with the self-reporting of food intake by

adults and children, which appear to be exacerbated in obese children (Maffeis et al., 1994). Hence, it appears that any results obtained about diet from children may be suspect, particularly if the variable of interest (body fat) may itself affect the accuracy of the children's dietary records.

In this study three Tritrac accelerometers were used; one model T303 and two models T303A. As in the previous study, this is a very limited sample of the Tritrac accelerometers available. It is not known whether this small sample gives a fair representation of all Tritrac accelerometers. The average counts per day measured by the Tritrac in this study were very similar to in an earlier study, with similarly aged children, by Welk and Corbin (1995). This gives some indication of inter-unit reliability between the two studies.

Study 4

The meta-analysis encompassed a very wide range of age groups: from 3 months to 18 years. The range of ages of children in individual studies varied considerably: some studies considered children the same age only, whereas others included children aged from 5-16 years. This prevented testing the influence of age on the effect size. Hence, the relationship between age and the strength of the fat/activity relationship is not known. Gender was not related to the effect size. However, the strong influence of activity measure as a moderating variable may have masked any further moderator variables. Potential moderator or confounding variables include gender, socioeconomic status and age. An undetected or unanalysed

confounding or moderator variable is a problem. Further research is needed to test for such variables.

Implications

There is considerable evidence from the results of this thesis that heart rate is not an appropriate method for assessing the spontaneous short bursts of activity that are typical in childhood. It is therefore recommended that heart rate should not be used as a criterion variable in any validation studies for potential activity measures. Behavioural measures, namely motion counters, are the ideal method for the assessment of physical activity in children.

Previous research has purported to show that children's activity levels are extremely low (Armstrong et al., 1990; Gilbey and Gilbey, 1995). However, much of this previous research has used heart rate methodologies to assess activity levels. In the light of the research in this thesis studies should be carried out using the more appropriate method of motion counters. This will ascertain whether children's activity levels are as low as these studies lead us to believe or whether heart rate methodologies may have missed some of the spontaneous bursts of activity typical of children. Similarly the relationship between children's activity levels and various health outcomes, e.g. cholesterol levels, need to be re-examined using behavioural measures to measure activity levels. Accelerometry would be the ideal method as it allows the quantification of different aspects of activity (frequency, intensity, duration and total activity), all of which may be related to the health outcome.

Motion counters have been objectively validated during a variety of activities. They clearly show a negative relationship between levels of body fat and current activity levels, and levels of aerobic fitness and current activity levels. The direction of causation in both relationships remains unclear. Whether inactivity causes increases in body fat and decreases in aerobic fitness, or whether inactivity is a result of high body fat or low aerobic fitness cannot be concluded from this research. To answer these questions a longitudinal study, measuring changes in both variables over a prolonged period of time, is needed.

These studies indicate that total activity is at least as important as moderate and vigorous activity, in moderating levels of body fat and aerobic fitness. The relative importance of total, low intensity and moderate/vigorous activity to fitness, fatness and other health outcomes needs to be explored further. It is possible that total activity is generally only high in children with relatively high levels of moderate and vigorous activity. However, previous research indicates that total activity is the important factor in weight control. Epstein et al. (1982) assigned obese 8-12 year old children to either a programmed aerobic exercise group or lifestyle exercise group. The lifestyle and aerobic exercise programmes were isocaloric. However, whereas the aerobic group were required to exercise at set intensities, the lifestyle group incorporated exercise into normal daily life, e.g.: walking; cycling; and using the stairs. Furthermore the lifestyle group could accumulate exercise throughout the day. The degree to which the children were overweight decreased in all groups during treatment. However, at the 6 month and 17 month follow-ups only the lifestyle exercise

group had maintained the decrease in weight. This indicates that although both programmes were effective in reducing weight, the lifestyle change intervention programme led to greater adherence, whereas structured exercise was abandoned.

Activity is an important factor for controlling children's body fat levels. In growing children caloric restriction can only be undertaken with care (Keller and Stevens, 1996). The causes of fatness in children are complex (Muecke et al., 1992). Inactivity is only one of the factors linked with fatness, but it may be one of the most easily modifiable. Hence, inactivity should be the first thing to address in slightly or moderately overfat children. Recent evidence has shown that it is healthier to be fat and fit than thin and unfit (Barlow et al., 1995). So, even if the increased activity levels do not reduce body fat to desirable levels they may still lead to improved present and/or future health.

Future research

Body fat levels are just one health factor that may be related to activity levels in children. As it is only now possible to measure physical activity in childhood with accuracy, many other questions can be addressed. For example, the tracking of physical activity throughout childhood and into adulthood.

The pedometer can be used in large scale studies to assess the degree of tracking of total activity. Smaller studies can use the Tritrac to assess changes in patterns of activity as children grow into adults. Total activity

changes can be appraised in relation to frequency, duration or intensity of activity. Where total activity does not change, it would be possible to explore the various facets of the total activity picture. Examination of the data of subjects who maintain, increase or decrease their activity levels and the changes in the pattern of their daily activity as they grow older may give an insight into how to best increase/maintain activity in those people where activity levels drop off.

The tracking of activity and body fat levels can be analysed simultaneously. This may show if activity and body fatness track to a similar extent. The degree of tracking of activity levels may differ according to the child's degree of fatness. If this is true the points at which interventions are necessary can be identified. It will also be possible to pinpoint the stages at which interventions are most effective. Effective and timely interventions aimed at improving the activity patterns of children may derail the tracking of high body fat levels.

Children with one or both parents obese are at increased risk of obesity (Stunkard, 1980). However, the extent to which this is a genetic predisposition and the extent to which it is related to environmental factors, e.g. physical activity levels and diet, is not clear. The Tritrac would allow the examination of the overall activity patterns of children at high and low risk of obesity. This would show what, if any, aspects of the activity pattern differ between normal weight children with varying risk of obesity. If their activity patterns do differ, interventions focusing on narrowing these differences may prevent the high risk children becoming obese, or reduce the degree of obesity when it does occur.

People who live in underprivileged regions have a higher prevalence of coronary heart disease than those living in more affluent areas (Freeman et al., 1990). Freeman et al. (1990) showed that this was reflected in a higher prevalence of risk factors, including physical inactivity, present in children living in these regions. The physical activity ratings were based on thirty minutes of continuous activity. Accumulated activity and low intensity activity was not measured. Accumulated activity may be more important than continuous bouts of aerobic activity regarding children's health. Hence, the activity patterns of children living in underprivileged areas compared to children living in other areas should be explored further. The availability of a cheap reliable method for measuring activity in larger groups of people, such as the pedometer, would allow this question to be addressed on a large scale.

The time-sampling nature of the Tritrac may reveal if people on an exercise programme compensate by decreasing spontaneous activity at other times during the day. Additionally, when studies employ training programmes the adherence to duration and intensity instructions can be assessed using time sampling monitors. Both the pedometer and the Tritrac can be used to quantify the increase in physical activity in lifestyle-type activity programmes or to regulate activity levels during rehabilitation from coronary heart disease or other illnesses. The pedometer has the added advantage that people can regulate their own activity level and aim for a given target of *total* activity per day.

There is some concern over the amount of exercise children get during their school PE lessons (Sallis and McKenzie, 1991). Research in this

area has used heart rate monitoring (e.g. Klausen et al., 1986). However, an observation study has also shown that activity levels of children are reduced during organised activities as opposed to free-play activities (Corbin and Fetcher, 1968). Motion counters can be used to further examine the contribution of PE lessons to a child's activity levels. They could also be used to assess if the teaching of ball skills etc. to young children had a positive effect on activity levels outside formal PE lessons.

Children spend a large amount of their free time watching television (Anderson et al., 1998). There is evidence for a weak inverse relationship between television watching and physical activity levels of young children (DuRant et al., 1994). Does the total physical activity of children who watch a lot of television reduce purely due to the displacement of other activities while watching television, or does physical activity reduce during the rest of the day as well? Are children who watch more television more prone to sedentary activities during the remainder of their free time, compared to children who do not watch excessive amounts of television? Time sampling accelerometers, combined with self-report (or parent report) of television watching, would answer this question.

What constitutes normal levels of physical activity for children with different ages? Rowland (1990) asks if a normal curve for physical activity could be established using a standardised method for assessing activity. This would make it possible for doctors to assess children's activity levels and identify children at risk. Due to its potential for use on a large scale the pedometer would be the ideal tool, both for creating normal values and for identifying children whose overall activity fell below normal values.

There has been a wealth of research regarding the relationship between physical activity levels and aerobic fitness in both children (Morrow and Freedson, 1994) and adults (Blair et al., 1989b; Young and Steinhardt, 1993; Anderson and Haraldsdottir, 1995). However, very little research has focused on the effects of physical activity levels on other aspects of fitness. What are the effects of habitual activity levels on muscle strength, muscle endurance, anaerobic power and flexibility? How do the benefits of physical activity on these aspects of fitness differ between pre-pubertal children, pubertal children, post-pubertal children and adults? Do similar activity thresholds as those provided for aerobic fitness provide benefits in other aspects of fitness?

Initiatives to increase people's physical activity levels include the provision of facilities, e.g. leisure centre, parks. What is the effect of these provisions on the activity levels of people in the community? Does the provision of more opportunities for physical activity actually increase people's physical activity levels. The activity levels of a community of people could be assessed prior to and following the provision of amenities for increased physical activity. This would allow the identification of the amenities most effective for increasing physical activity levels, for use in future initiatives.

In adults physical activity has been shown to reduce the risk of chronic disease, e.g. coronary heart disease, hypertension, atherosclerosis (Bouchard et al., 1994). However, the effects of physical activity on the various forms of cancer are not understood. The strongest evidence is for a link between physical activity and colon cancer; approximately three

quarters of published studies addressing this question have shown that physically active people have a lower incidence of colon cancer than inactive people (Nieman, 1998). The availability of accelerometry for assessing all facets of activity, or pedometry for assessing activity levels in large numbers of people objectively, may allow more insight into the effects, if any, of physical activity on the risk of this and other forms of cancers.

The Tritrac may be the ideal tool for assessing the relationship between physical activity and bone density. The magnitude of the vertical vector should directly relate to the degree and intensity of weight-bearing activity. As weight-bearing types of physical activity are considered to be the most beneficial to bone health (Marcus & Carter, 1988), potentially the vertical vector output from the Tritrac may be the most appropriate measure of relevant activity. This also has potential in the evaluation of the effects of different types of activity on bone density maintenance or loss in pre-menopausal, menopausal and post-menopausal women.

As outlined above, the ability to measure physical activity accurately and objectively in childhood will allow important questions relating to health and activity to be addressed in diverse areas of future research.

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Appendix A

Letters of informed consent

STUDY 1 (CHAPTER 3)

Dear Parent/Guardian,

I am a postgraduate research student at the University of Wales, Bangor. My research involves the validation of different methods of assessing physical activity in children.

In order to do this I need 40 volunteers, aged 8-10 years. The children taking part in this study will be required to run on a motor driven treadmill at various speeds, play catch, hopscotch and do some colouring. Transport to and from the University will be provided. During the test his/her heart rate will be monitored continuously and a lightweight mouthpiece will be worn to allow the analysis of expired gases. In addition three small pedometers will be worn on a belt around the waist, ankle or wrist to count steps.

There is negligible risk involved in this study. From our experience children find this visit rewarding and highly interesting. Information from the tests will be made available to you. Results obtained may be used for publication with complete anonymity being assured.

If you have any questions regarding the test please feel free to contact me, or my supervisor Dr. Roger Eston.

If your child would like to volunteer for this study and you give your consent could you please sign below. Your child's participation in this study is greatly appreciated.

Yours faithfully

Ann Rowlands

I certify that my child is participating in this activity of his/her own free will and that either I or my child may discontinue participation at any time.

Name of Child _____ Date of Birth _____

Signature of Parent or Guardian _____ Date _____

Telephone no. _____

Address _____

STUDY 3 (CHAPTER 5)

Dear Parent/Guardian,

Assessment of Physical Activity in Children

I am a postgraduate research student at the University of Wales, Bangor. My research involves the assessment of physical activity in children.

I am looking for 60 volunteers aged 8-10 years. The children taking part in this study will be required to wear a small activity monitor (about the size of a pack of cards), on a belt around the waist, for 1 week. During one day his/her heart will also be monitored. Prior to activity measurement body fat will be estimated using skinfolds. Following the study, fitness will be assessed from a treadmill test in the laboratory at the University. Transport to and from the University will be provided.

There is negligible risk involved in this study. From our experience children find participation in these studies rewarding and highly interesting. Information from the tests will be made available to you. Results obtained may be used for publication with complete anonymity being assured.

If you have any questions regarding the test please feel free to contact me or my supervisor Dr. Roger Eston.

If your child would like to volunteer for this study and you give your consent could you please sign below. Your child's participation in this study is greatly appreciated.

Yours faithfully,

Ann Rowlands

I certify that my child is participating in this activity of his/her own free will and that either I or my child may discontinue participation at any time.

Name of Child _____ Date of Birth _____

Signature of Parent or Guardian _____ Date _____

Telephone no. _____

Address _____

Child's height _____ Child's weight _____

STUDY 3 (CHAPTER 5): FITNESS TEST*Explanation*

I understand that my child will walk/run on a treadmill. The exercise will get harder as the test goes on. The test will end when a maximal effort has been obtained or if my child no longer wants to continue. Each test should be over in about ten minutes. Heart rate will be measured throughout the test.

Benefits

The benefits to me and my child include accurate information about his/her fitness compared to other children the same age.

Freedom of consent

My child and I have had an adequate chance to ask questions and understand that we may ask additional questions at any time.

I certify that my child is participating in this study of his/her own free will and that either I or my child may discontinue participation at any time.

Name of Child _____

Signature of Parent or Guardian _____

Date _____

Appendix B

Study 1: Validity of heart rate, pedometry and accelerometry for predicting the energy cost of children's activities

B1 Planned comparisons of the correlations with scaled oxygen uptake

B2 The use of repeated measures in regression analysis

B3 The combination of hip, ankle and wrist pedometry for the prediction of scaled oxygen uptake

B1 PLANNED COMPARISONS OF THE CORRELATIONS WITH SCALED OXYGEN UPTAKE

The correlations of two activity measures (2, 3) with oxygen uptake (1) were compared to see if one was significantly higher than the other. The differences between correlation coefficients were assessed using an adapted *t*-test (Hotelling, 1940). This test allows for the correlation between the two coefficients of correlation.

$$t = (r_{12} - r_{13}) \{ [(N - 3)(1 + r_{23})] / [2(1 - r_{23}^2 - r_{12}^2 - r_{13}^2 + 2r_{23}r_{12}r_{13})] \}^{0.5}$$

where *N* = sample size

1 = criterion measure (scaled oxygen uptake)

2 = alternative activity measure e.g. Tritrac_{xyz}

3 = second alternative activity measure e.g. heart rate

D of *F* = *N* - 3

Worked example

*r*₁₂ = correlation between scaled oxygen uptake and Tritrac_{xyz} (0.908)

*r*₁₃ = correlation between scaled oxygen uptake and heart rate (0.799)

*r*₂₃ = correlation between Tritrac_{xyz} and heart rate (0.791)

$$t_{167} = (0.908 - 0.799) \{ [(170 - 3)(1 + 0.791)] / [2(1 - 0.791^2 - 0.908^2 - 0.799^2 + (2 \times 0.791 \times 0.908 \times 0.799))] \}^{0.5}$$

$$= 5.479$$

critical *t*_∞ for α = 0.001 is 3.291

Summary of results

Activity Measures			Correlations			
1	2	3	<i>r</i> ₁₂	<i>r</i> ₁₃	<i>r</i> ₂₃	<i>t</i>
<i>S</i> \dot{V} O ₂	Tritrac _{xyz}	Heart rate	0.908	0.799	0.791	*5.479
<i>S</i> \dot{V} O ₂	Tritrac _{xyz}	Hip pedometer	0.908	0.806	0.910	*7.621
<i>S</i> \dot{V} O ₂	Tritrac _{xyz}	WAM	0.908	0.780	0.734	*5.832
<i>S</i> \dot{V} O ₂	Tritrac _{xyz}	Tritrac _z	0.908	0.891	0.987	*3.329
<i>S</i> \dot{V} O ₂	WAM	Heart rate	0.780	0.799	0.684	0.599
<i>S</i> \dot{V} O ₂	Hip pedometer	Heart rate	0.806	0.799	0.622	0.229

S \dot{V} O₂ = Scaled oxygen uptake

N varies from 159 to 177 due to listwise deletion for missing values

* significant *P* < 0.001

The Tritrac accelerometer had significantly higher correlations with scaled oxygen uptake than any other activity measure.

Unregulated activities only

Activity Measures			Correlations			
1	2	3	r_{12}	r_{13}	r_{23}	t
$\dot{V}O_2$	Hip pedometer	Heart rate	0.921	0.858	0.883	*2.926
$\dot{V}O_2$	Hip pedometer	WAM	0.921	0.852	0.854	*2.939

 $N = 75$ *significant $P < 0.01$

During unregulated activities the pedometer had a significantly higher correlation with scaled oxygen uptake than either the heart rate monitor or the WAM accelerometer.

B2 THE USE OF REPEATED MEASURES IN REGRESSION ANALYSIS

Regression analysis was used in order to predict scaled oxygen uptake (dependent variable, Y) from an alternative measure of activity (independent variable, X). In standard regression analysis it is assumed that each pair of measures is taken from different subjects. However, in this study, repeated-measures were taken from each subject for seven different activities: walking at 4 kph; walking at 6 kph; running at 8 kph; running at 10 kph; playing catch; hopscotch; sitting and crayoning.

Donner and Cunningham (1984) have produced a paper concerning the statistical implications of repeated-measures linear regression, some of which will be outlined here. They show that the method of taking repeated measures on the same subject may violate the assumptions of least-squares regression. This is because ordinary least-squares methods assume that there is no correlation among the observations (Y) after allowing for dependence on the explanatory variables. When several measures are taken on one subject, as in repeated-measures regression, this assumption may be invalid as those measures will tend to be more similar than measures taken on different subjects. However, if the independent variable (X) completely explains the within-subject clustering the assumption will not be violated.

If within-subject clustering is present in the data there will be a correlation between random errors (ρ) on the same subject. If this is the case the ordinary least-squares regression equation can still be used for the purpose of prediction, but standard errors of the estimators will be invalid (Donner and Cunningham, 1984). The hypothesis $\rho = 0$ can be tested by comparing the residual variation in Y between subjects to the residual variation within subjects. If the null hypothesis is rejected it implies that the “ Y -values for a randomly selected subject are all high or low by some amount relative to the population mean of Y , a tendency which persists even after adjusting for X . The presence of such a tendency is the source of the within-subject clustering” (Donner and Cunningham, 1984).

If the null hypothesis is rejected the degree to which the seven activities measured on one subject are more alike than the seven activities measured on different subjects can be calculated. This is the within-subject correlation (ρ_x) with respect to the observed values of X (independent variable). If the variation among subjects is greater than that within subjects ρ_x will be positive. This will be the case when values of Y are randomly selected at each value of X . In the above study, though, the values of X (the measures of activity) were pre-selected and not random. This may have led to a greater variation within subjects than between subjects. This leads to a negative ρ_x . If the first test shows within subject clustering and ρ_x is positive, the consequences may be quite serious as a statistically non-significant relationship between X and Y may appear to be significant. However, if the first test shows within-subject clustering, but ρ_x is negative a significant relationship between X and Y , elicited from the standard regression analysis, will be even more significant (Donner and Cunningham, 1984).

The following, taken from Donner and Cunningham (1984), shows the methodology for testing the hypothesis $\rho = 0$ and also for calculating ρ_x . A

worked example for the regression analysis between Tritrac_{xyz} and scaled oxygen consumption follows. A summary of the results for each of the different activity monitors is shown in Table 3.

Table 1 shows the values needed for the test. The between-subjects analysis of variance breakdown provides the (yy) and (xx) columns. The (xy) column is the corresponding breakdown of the cross-product term XY . Donner and Cunningham (1984) provide a full definition of each of these terms.

Table 1. Sum of squares and products

Source	<i>D of F</i>	(yy)	(xx)	(xy)
Between subjects (<i>B</i>)	<i>k</i> -1	$(yy)_B$	$(xx)_B$	$(xy)_B$
Within subjects (<i>W</i>)	<i>N</i> - <i>k</i>	$(yy)_W$	$(xx)_W$	$(xy)_W$
Total (<i>T</i>)	<i>N</i> -1	$(yy)_T$	$(xx)_T$	$(xy)_T$

k = number of subjects

n = number of measurements on each subject

N = number of observations (*nk*)

First, the residual variance between and within subjects has to be calculated:

$$S_b^2 = [(yy)_B - (xy)_B^2 / (xx)_B] / (k - 2)$$

$$S_w^2 = [(yy)_W - (xy)_W^2 / (xx)_W] / (N - k - 1)$$

The null hypothesis $\rho = 0$ can then be tested:

$$F = S_b^2 / S_w^2 \quad \text{Degrees of freedom} = (k - 2) \text{ and } (N - k - 1)$$

The within-subject correlation (ρ_x) is calculated as follows:

$$\rho_x = \{n[(xx)_B / (xx)_T] - 1\} / (n - 1)$$

Worked Example:

X = Tritrac_{xyz} counts

Y = Scaled oxygen uptake

Table 2. Sum of squares and products for Tritrac (*X*) and scaled oxygen uptake (*Y*)

Source	<i>D of F</i>	(yy)	(xx)	(xy)
Between subjects (<i>B</i>)	25	6552.23	8826805	1.8×10^{11}
Within subjects (<i>W</i>)	151	99940.01	6.8×10^8	4.4×10^{12}
Total (<i>T</i>)	176	106492.2	6.9×10^8	4.6×10^{12}

$$S_b^2 = [(6552.23) - (1.8 \times 10^{11})^2 / (8826805)] / (26 - 2)$$

$$= -1.529 \times 10^{14}$$

$$S_w^2 = [(99940.01) - (4.4 \times 10^{12})^2 / (6.8 \times 10^8)] / (176 - 25 - 1)$$

$$= -1.898 \times 10^{14}$$

$$F_{24,150} = -1.529 \times 10^{14} / -1.898 \times 10^{14}$$

$$= 0.806$$

Since $F(\text{crit})_{24,150} = 1.59$ ($\alpha = 0.05$) the null hypothesis can be accepted, i.e. there is no within-subject residual correlation. Hence, there is no need to correct the standard error attained by the ordinary least squares method for the effect of clustering.

Summary of results:

<i>X</i>	<i>Y</i>	S_b^2	S_w^2	<i>F</i>	<i>D of F</i>
Tritrac _x	$\dot{S}VO_2$	-1.044×10^{13}	-2.492×10^{13}	0.419	24, 150
Tritrac _y	$\dot{S}VO_2$	-2.353×10^{13}	-4.119×10^{13}	0.571	24, 150
Tritrac _z	$\dot{S}VO_2$	-1.042×10^{14}	-1.168×10^{14}	0.892	24, 150
WAM	$\dot{S}VO_2$	-3.255×10^{14}	-7.683×10^{14}	0.424	24, 150
Hip pedometer	$\dot{S}VO_2$	-5.222×10^{11}	-2.735×10^{11}	*1.909	24, 150
Ankle pedometer	$\dot{S}VO_2$	-2.046×10^{11}	-2.475×10^{11}	0.827	24, 150
Wrist pedometer	$\dot{S}VO_2$	-7.684×10^{10}	-1.480×10^{11}	0.519	24, 150
Heart rate	$\dot{S}VO_2$	-1.078×10^{11}	-7.399×10^{11}	0.146	23, 140

$\dot{S}VO_2$ = scaled oxygen uptake

*significant $P < 0.05$

The null hypothesis of no within-subject clustering can be accepted for all the above analyses with the exception of one. The within-subject residual correlation is significant for the regression equation predicting oxygen uptake from hip pedometry. We can estimate the value of this correlation:

$$\rho = (S_b^2 - S_w^2) / [S_b^2 + (n_0 - 1)S_w^2]$$

$$\text{where } n_0 = n \{1 - (xx)_B / [(xx)_T(k-1)]\}$$

$$n_0 = 7 \{1 - (16157.196) / [(1279828)(25)]\}$$

$$= 6.996$$

$$\rho = [(-5.222 \times 10^{11}) - (-2.735 \times 10^{11})] / [(-5.222 \times 10^{11}) + (5.996)(-2.735 \times 10^{11})]$$

$$= 0.115$$

As the values of X are controlled (by which activity was taking place) the variation between subjects will be greater than within subjects. This can be shown by calculating ρ_x :

$$\begin{aligned}\rho_x &= \{[7(16157.196)/1279828] - 1\}/6 \\ &= -0.152\end{aligned}$$

The negative value of ρ_x shows that the previously calculated standard error of prediction will be an overestimation. In this situation the unadjusted analysis lacks power and hence a significant result may be reported as non-significant. In this case, as the unadjusted analysis was already significant, we can safely conclude that adjusting for the within-subject correlation will not change the conclusions. We can calculate how much the standard error of prediction was inflated by multiplying by the inflation factor (IF).

$$\begin{aligned}IF &= [1 + (n - 1) \rho_x \rho]^{1/2} \\ &= [1 + (7 - 1)(-0.152)(0.115)]^{1/2} \\ &= 0.946, \text{ hence the adjusted standard error of prediction} = 95\% \text{ of} \\ &\text{the initial calculated value.}\end{aligned}$$

Implications

In conclusion no within-subject clustering existed for all but one of the analyses. Hence, the standard regression analysis did not violate any assumptions. The regression equation using hip pedometry to predict scaled oxygen uptake the within-subject residual correlation was significant ($\rho = 0.115$). However, the variation within subjects was greater than between subjects. This indicated that the standard regression analysis lacked power and the standard error of prediction was overestimated. The conclusion that all the alternative measures of activity explained a significant proportion of scaled oxygen uptake is unchanged.

B3 THE COMBINATION OF HIP, ANKLE AND WRIST PEDOMETRY FOR THE PREDICTION OF SCALED OXYGEN UPTAKE

It was hypothesised that pedometry may give a better estimate of scaled oxygen uptake if pedometers were located at several sites on the body, compared to just one worn on the hip. However, regression analysis (below) showed that combining results from pedometers at three locations did not provide a significantly better prediction of scaled oxygen uptake than the hip pedometer alone.

Variables Entered/Removed^b

Model	Variables Entered	Variables Removed	Method
1	pedometer hip ^a	.	Enter
2	pedometer ankle ^a	.	Enter
3	pedometer wrist ^a	.	Enter

a. All requested variables entered.

b. Dependent Variable: scaled oxygen uptake (ml/kg**0.75/min)

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.806 ^a	.650	.648	14.5971	.650	324.790	1	**	.000
2	.807 ^b	.651	.647	14.6172	.001	.519	1	**	.472
3	.807 ^c	.651	.645	14.6524	.000	.164	1	**	.686

a. Predictors: (Constant), pedometer hip

b. Predictors: (Constant), pedometer hip, pedometer ankle

c. Predictors: (Constant), pedometer hip, pedometer ankle, pedometer wrist

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	26.572	1.993		13.336	.000
	pedometer hip	.254	.014	.806	18.022	.000
2	(Constant)	26.712	2.005		13.325	.000
	pedometer hip	.313	.084	.995	3.740	.000
	pedometer ankle	-5.97E-02	.083	-.192	-.720	.472
3	(Constant)	26.397	2.155		12.251	.000
	pedometer hip	.309	.084	.982	3.658	.000
	pedometer ankle	-6.38E-02	.084	-.205	-.762	.447
	pedometer wrist	1.299E-02	.032	.032	.405	.686

a. Dependent Variable: scaled oxygen uptake (ml/kg**0.75/min)

Appendix C

Study 2: Validity of heart rate, pedometry and accelerometry for estimating the energy cost of activity in Hong Kong Chinese boys

C1 Comparison of Hong Kong and United Kingdom correlations between activity measures and scaled oxygen uptake

C2 Comparison of correlated correlation coefficients: scaled oxygen uptake with hip pedometer, WAM and heart rate

C1 COMPARISON OF HONG KONG AND UNITED KINGDOM CORRELATIONS BETWEEN ACTIVITY MEASURES AND SCALED OXYGEN UPTAKE

To allow the assessment of whether the correlations between each activity measure and \dot{SVO}_2 from the HK sample were significantly different to those from the UK sample the correlations were transformed to Fisher's z_r 's. Untransformed correlation coefficients are not normally distributed, transforming the correlations to Fisher's z_r approximates a normal distribution. The following equation was used to test if the effect sizes differed according to nationality. The result is given as a Z score. Due to the number of comparisons being made alpha was reduced to 0.01 to control for Type I error.

$$Z = (z_{r1} - z_{r2}) / \{ [1/(N_1 - 3)] + [1/(N_2 - 3)] \}^{0.5}$$

Snedecor and Cochran (1967, p.186)

where N_1 = sample size for HK
 N_2 = sample size for UK
 z_{r1} = Fisher's z_r for HK
 z_{r2} = Fisher's z_r for UK

Worked Example

All activities
 \dot{SVO}_2 and hip pedometer

HK	r_1	= 0.857	N_1	= 146
	z_{r1}	= 1.282		
UK	r_2	= 0.860	N_2	= 177
	z_{r2}	= 1.293		

$$Z = (1.282 - 1.293) / \{ [1/(146 - 3)] + [1/(177 - 3)] \}^{0.5}$$

$$= -0.097$$

The two tailed P associated with a Z of 0.097 is 0.920. There is no significant difference between the correlation for HK and that for UK.

Summary of results

All activities combined						
Activity measure	z_{r1}	N_1	z_{r2}	N_2	Z	P
Dependent variable = \dot{SVO}_2						
Tritrac _{xyz}	1.774	147	1.516	177	2.290	0.022
Tritrac _x	1.313	147	1.245	177	0.604	0.548
Tritrac _y	1.505	147	1.358	177	1.305	0.190
Tritrac _z	1.673	147	1.427	177	2.184	0.029
WAM	1.290	147	1.045	166	2.142	0.032
Heart rate	1.408	144	1.096	170	2.728	0.006*
Hip pedometer	1.282	146	1.293	177	0.097	0.920
Ankle pedometer	1.182	144	1.069	177	0.997	0.317
Wrist pedometer	0.293	146	0.802	177	4.510	0.000†

*The correlation between \dot{SVO}_2 and heart rate was significantly higher for the HK sample

†The correlation between \dot{SVO}_2 and wrist pedometry was significantly higher for the UK sample.

The remaining Z scores were not significant, indicating that the correlations between the activity measures and \dot{SVO}_2 for the HK sample did not differ significantly from those for the UK sample.

Treadmill activities alone						
Activity measure	z_{r1}	N_1	z_{r2}	N_2	Z	P
Dependent variable = \dot{SVO}_2						
Tritrac _{xyz}	1.689	84	1.389	99	1.988	0.047
Tritrac _x	1.074	84	1.008	99	0.437	0.660
Tritrac _y	1.211	84	0.950	99	1.730	0.084
Tritrac _z	1.564	84	1.305	99	1.717	0.085
WAM	1.124	84	0.852	91	1.766	0.077
Heart rate	1.437	81	1.056	95	2.475	0.013
Hip pedometer	1.025	83	1.050	99	0.165	0.865
Ankle pedometer	0.833	81	0.883	99	0.328	0.741
Wrist pedometer	-0.045	83	0.175	99	1.453	0.147

All Z scores were not significant, indicating that the correlations between the activity measures and \dot{SVO}_2 for the HK sample did not differ significantly from those for the UK sample.

Unregulated play activities alone						
Activity measure	z_{r1}	N_1	z_{r2}	N_2	Z	P
	Dependent variable = $S\dot{V}O_2$					
Tritrac _{xyz}	1.689	63	1.630	78	0.341	0.734
Tritrac _x	1.494	63	1.313	78	1.045	0.294
Tritrac _y	1.623	63	1.644	78	0.121	0.904
Tritrac _z	1.583	63	1.623	78	0.231	0.818
WAM	1.380	63	1.263	75	0.669	0.503
Heart rate	1.225	63	1.286	75	0.349	0.726
Hip pedometer	1.666	63	1.596	78	0.404	0.689
Ankle pedometer	1.583	63	1.539	78	0.254	0.803
Wrist pedometer	1.166	63	1.313	78	0.849	0.395

All Z scores were not significant, indicating that the correlations between the activity measures and $S\dot{V}O_2$ for the HK sample did not differ significantly from those for the UK sample.

**C2 COMPARISON OF CORRELATED CORRELATION
COEFFICIENTS: SCALED OXYGEN UPTAKE WITH HIP
PEDOMETER, WAM AND HEART RATE**

The above method could not be used to assess whether the correlation between the hip pedometer and $S\dot{V}O_2$ during unregulated activities was significantly higher than those of WAM and heart rate (HR) with $S\dot{V}O_2$, as all three variables (hip pedometer, WAM and HR) were correlated with the same data ($S\dot{V}O_2$). Meng et al. (1992) present a method for comparing correlations when they are correlated. The result is given as a Z score.

$$Z = (z_{r_1} - z_{r_2}) \{(N - 3) / [2(1 - r_x)h]\}^{0.5}$$

where N = the number of subjects

z_{r_1} = Fisher's z_r for first predictor variable with dependent measure

z_{r_2} = Fisher's z_r for second predictor variable with dependent measure

r_x = Correlation between two predictor variables

$$h = (1 - \bar{r}^2) / (1 - r_x^2)$$

where $f = (1 - r_x) / [2(1 - \bar{r}^2)]$

$$\bar{r}^2 = (r_1^2 + r_2^2) / 2$$

Worked Example

UK

Pedometer and $S\dot{V}O_2$ $r_1 = 0.921$ $z_{r_1} = 1.596$

HR and $S\dot{V}O_2$ $r_2 = 0.858$ $z_{r_2} = 1.286$

HR and pedometer $r_x = 0.883$

$$N = 78$$

$$\bar{r}^2 = (0.921^2 + 0.858^2) / 2$$

$$= 0.792$$

$$f = (1 - 0.883) / [2(1 - 0.792)]$$

$$= 0.281$$

$$h = [1 - (0.281 \times 0.792)] / (1 - 0.792)$$

$$= 3.737$$

$$Z = (1.596 - 1.286(78 - 3) / [2(1 - 0.883)3.737])^{0.5}$$

$$= 2.871$$

The two tailed P associated with a Z score of 2.871 is 0.004. The correlation between hip pedometry and $S\dot{V}O_2$ is significantly higher than the correlation between HR and $S\dot{V}O_2$.

Summary of results

Predictor variable 2	z_{r1}	z_{r2}	r_x	N	\bar{r}^2	f	h	Z	P
HK									
HR	1.666	1.225	0.823	63	0.787	0.415	3.161	3.229	0.001
WAM	1.666	1.380	0.906	63	0.821	0.263	4.380	2.441	0.014
UK									
HR	1.596	1.286	0.883	78	0.792	0.281	3.737	2.871	0.004
WAM	1.596	1.263	0.854	78	0.787	0.343	3.428	2.882	0.004

Predictor variable 1 = Pedometer

Dependent variable = $S\dot{V}O_2$

The correlations of hip pedometer counts with $S\dot{V}O_2$ are significantly higher than those of WAM counts with $S\dot{V}O_2$ (HK $P < 0.05$, UK $P < 0.01$), or HR with $S\dot{V}O_2$ ($P < 0.01$).

Appendix D

Study 3: The relationship between activity levels, aerobic fitness, and body fat in 8-10 year old children

D1 Comparison of boys and girls correlations between activity and fitness and fatness

D2 Scatterplots showing relationships between activity and fitness and fatness for boys and girls

D3 Comparison of two correlated correlation coefficients: Tritrac and scaled oxygen uptake; and pedometer and scaled oxygen uptake

D4 Contrasts among correlated correlation coefficients

D5 Feedback to parents

D1 COMPARING BOYS AND GIRLS CORRELATIONS BETWEEN ACTIVITY AND FITNESS AND FATNESS

Results for males and females were compared to assess if the effect sizes were significantly heterogeneous, or could be considered similar. The methodology used was the same as shown in Appendix C1.

$$Z = (z_{r1} - z_{r2}) / \{ [1/(N_1 - 3)] + [1/(N_2 - 3)] \}^{0.5}$$

Snedecor and Cochran (1967, p.186)

where N_1 = sample size for boys
 N_2 = sample size for girls
 z_{r1} = Fisher's z_r for boys
 z_{r2} = Fisher's z_r for girls

Worked Example

Sum Tritrac and fitness

Boys	r_1	= 0.643	N_1	= 16
	z_{r1}	= 0.763		
Girls	r_2	= 0.546	N_2	= 16
	z_{r2}	= 0.613		

$$Z = (0.763 - 0.613) / \{ [1/(16 - 3)] + [1/(16 - 3)] \}^{0.5}$$

$$= 0.382$$

The two tailed P associated with a Z of 0.382 is 0.704. There is no significant difference between the effect size for boys and that for girls.

Summary of results

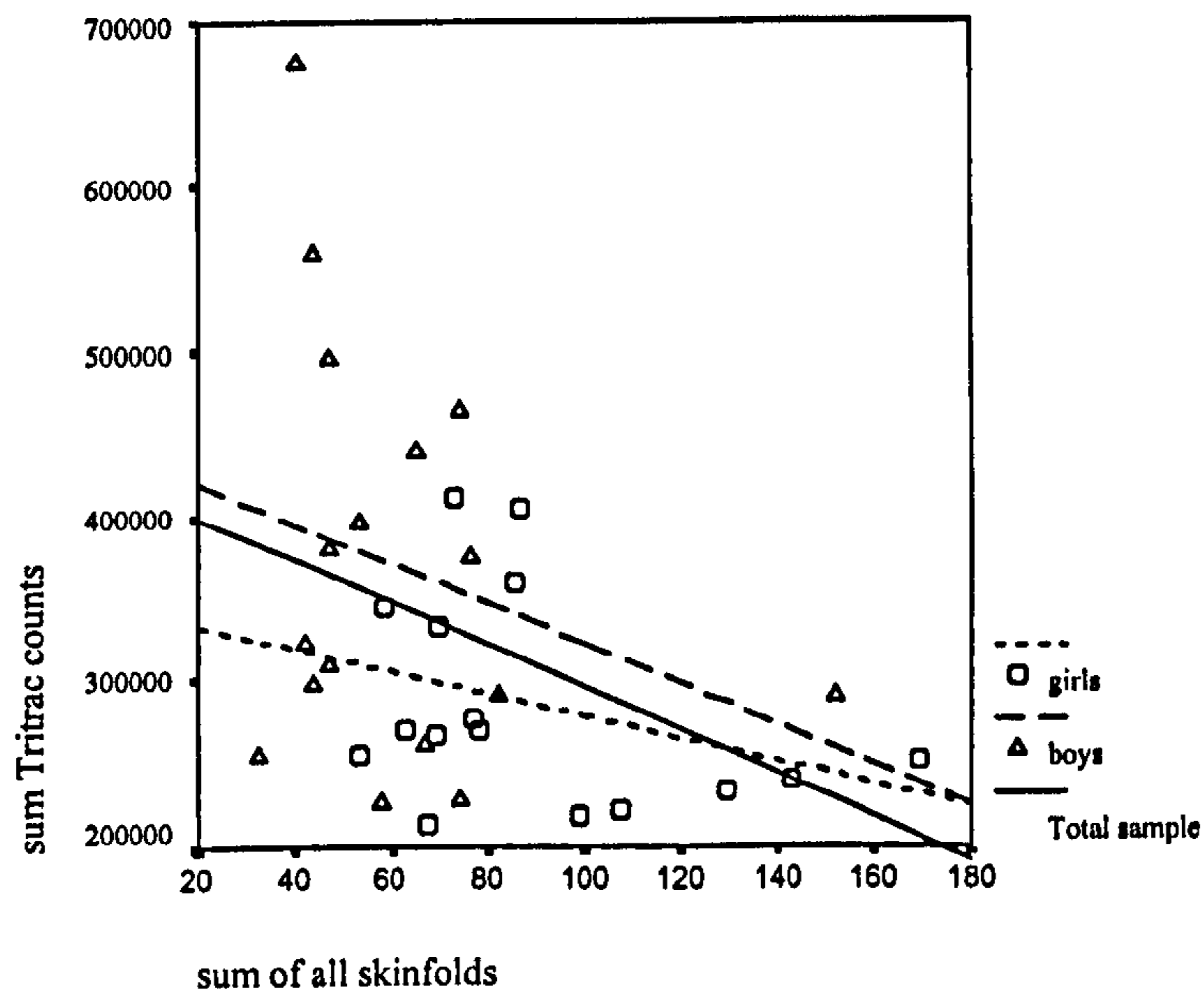
Activity measure	z_{r1}	N_1	z_{r2}	N_2	Z	P
Dependent variable = fitness						
Sum Tritrac	0.763	16	0.613	16	0.382	0.704
≥ mod Tritrac	0.701	16	0.772	16	0.181	0.857
≥ vig Tritrac	0.589	16	0.603	16	0.036	0.968
pedometer counts	0.555	14	0.664	13	0.249	0.803
Dependent variable = fatness (log Σ7 skinfolds)						
Sum Tritrac	-0.286	17	-0.328	16	0.109	0.912
≥ mod Tritrac	-0.250	17	-0.428	16	0.462	0.646
≥ vig Tritrac	-0.231	17	-0.405	16	0.457	0.464
pedometer counts	-0.225	15	-0.531	13	0.715	0.472

All the resulting Z scores were not significant, indicating that the effect sizes for boys did not differ significantly from those for girls.

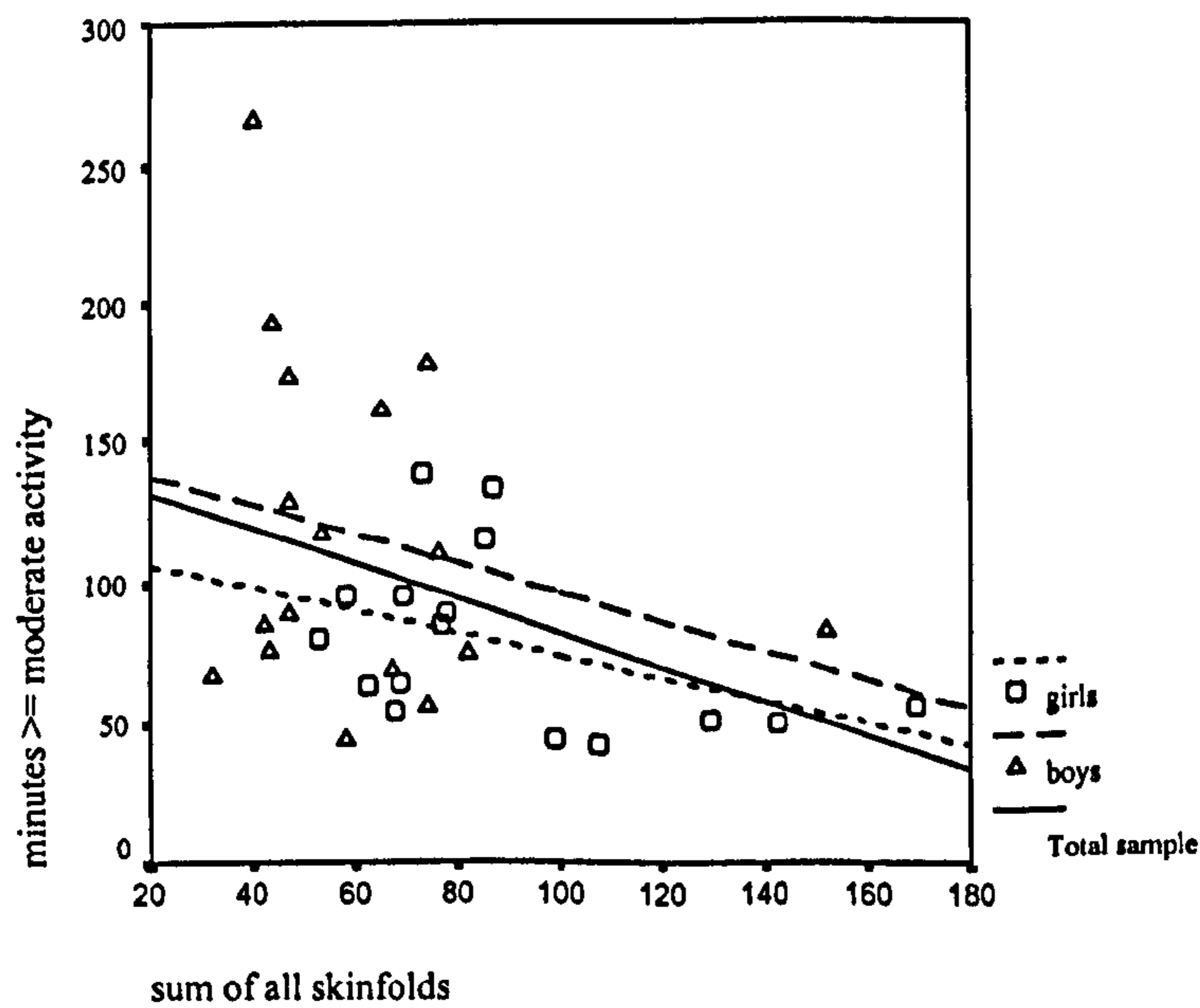
D2 SCATTERPLOTS SHOWING RELATIONSHIPS BETWEEN ACTIVITY AND FITNESS AND FATNESS FOR BOYS AND GIRLS

Activity-fatness scatterplots by gender and by total sample

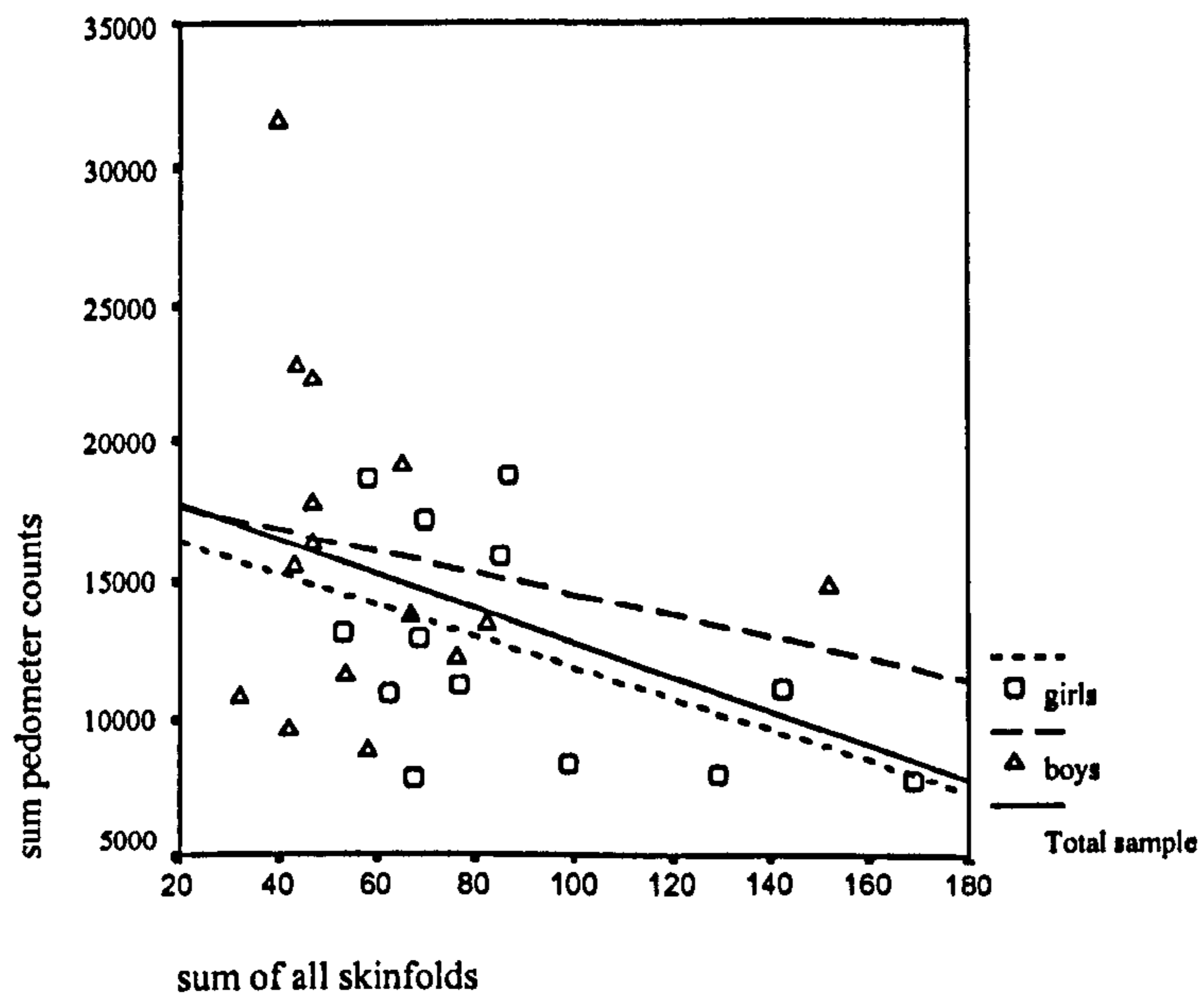
Sum Tritrac counts



Minutes > moderate activity, measured by the Tritrac

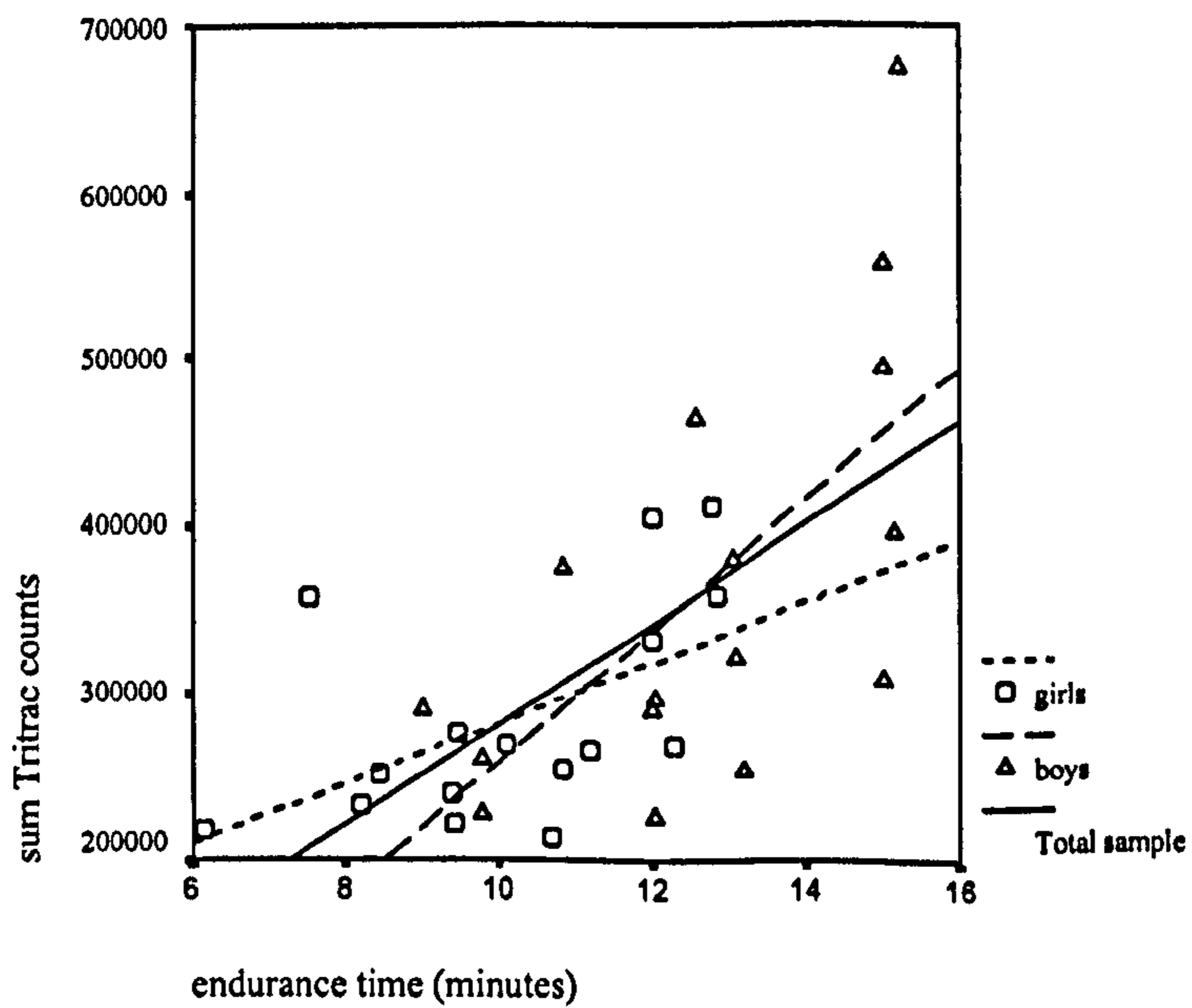


Pedometer counts

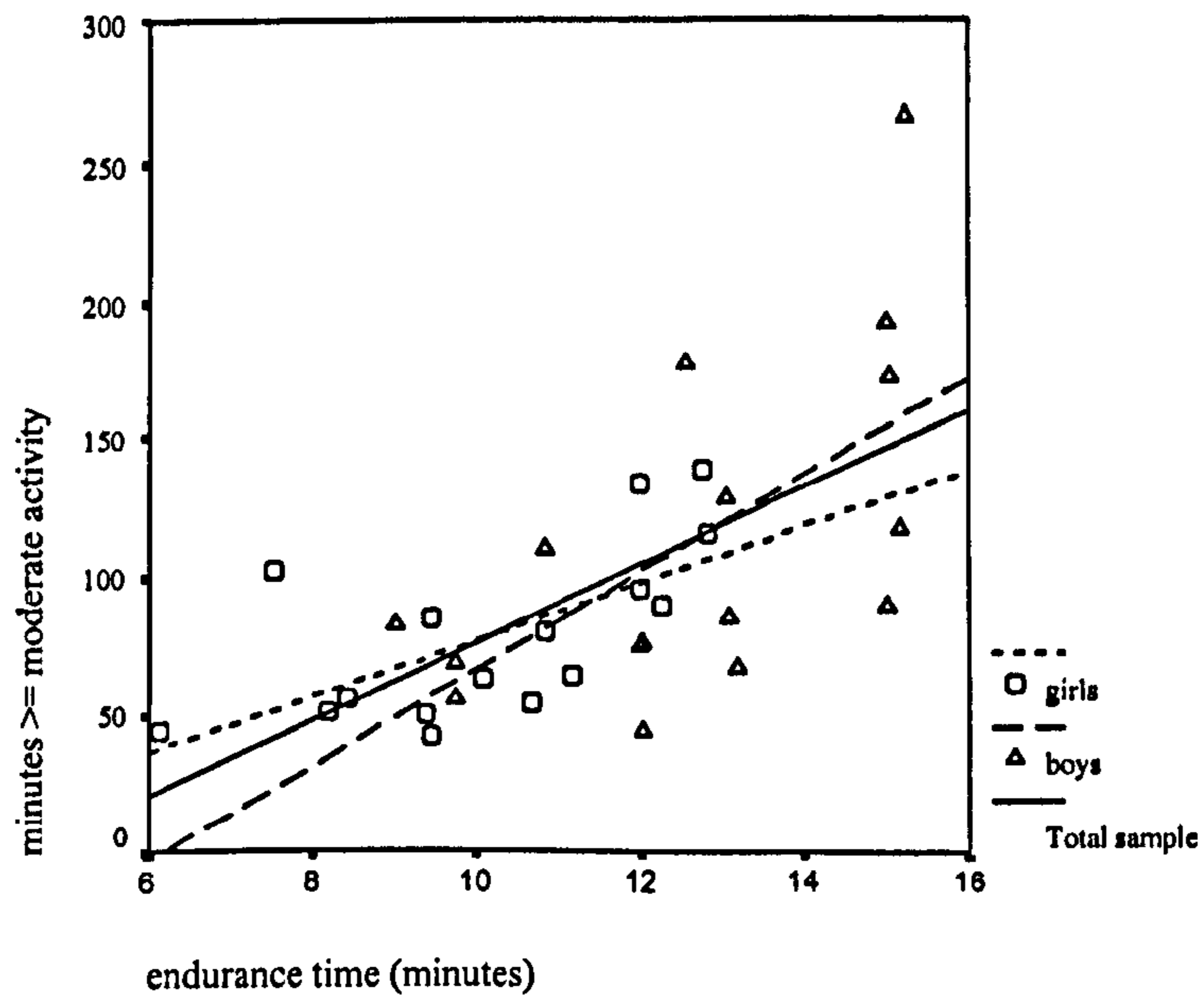


Activity-fitness scatterplots by gender and by total sample

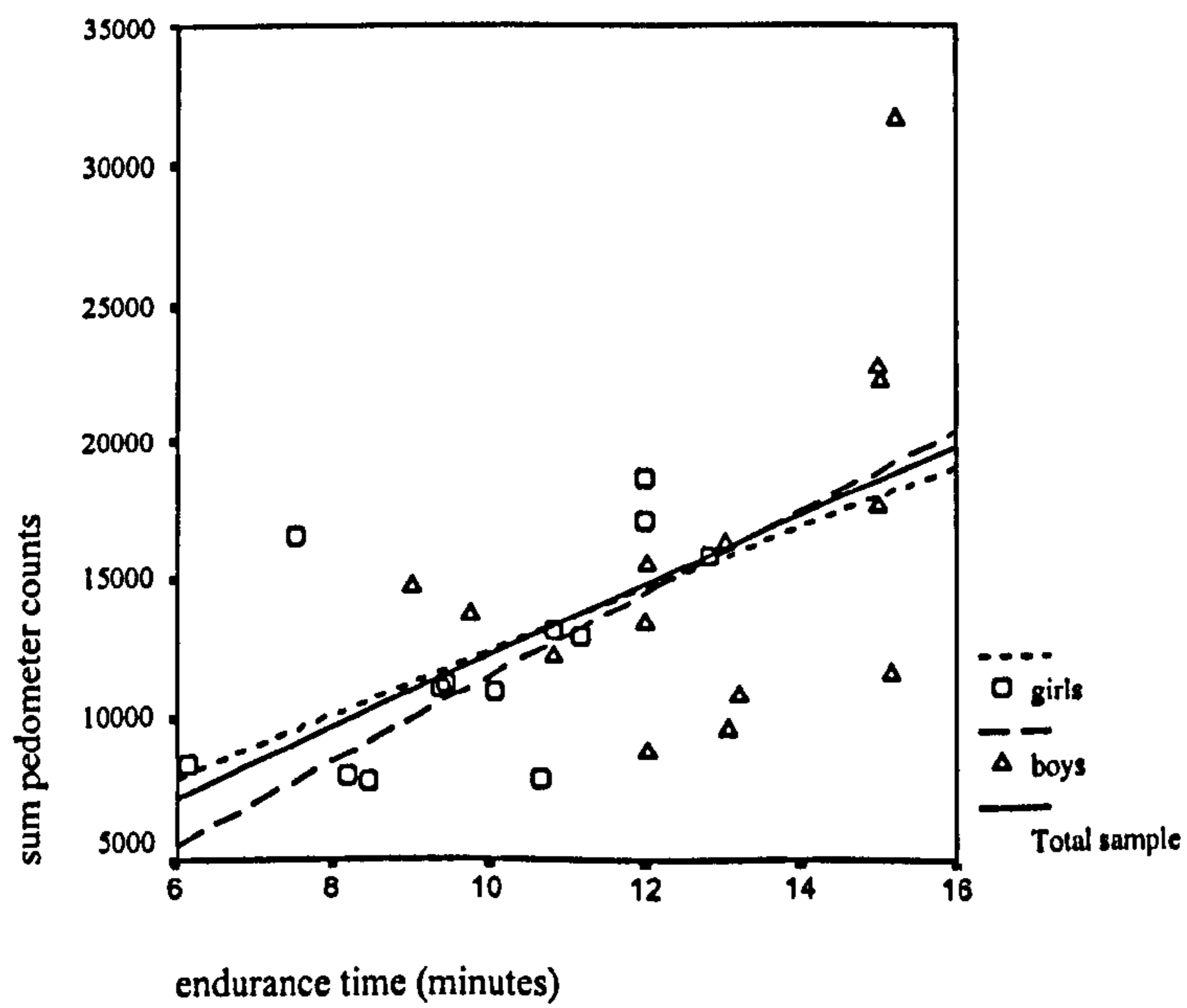
Sum Tritrac counts



Minutes > moderate activity, measured by the Tritrac



Pedometer counts



**D3 COMPARISON OF TWO CORRELATED CORRELATION
COEFFICIENTS: TRITRAC AND SCALED OXYGEN UPTAKE; AND
PEDOMETER AND SCALED OXYGEN UPTAKE**

The above method could not be used to assess whether there was a significant difference between the correlation of the Tritrac with the dependent measures and that from the pedometer as both these independent variables were correlated with the same data. Hence, the methodology used was the same as shown in Appendix C2.

$$Z = (z_{r_1} - z_{r_2}) \{(N - 3) / [2(1 - r_x)h]\}^{0.5}$$

where N = the number of subjects
 z_{r_1} = Fisher's z_r for first predictor variable with dependent measure
 z_{r_2} = Fisher's z_r for second predictor variable with dependent measure
 r_x = Correlation between two predictor variables

$$h = (1 - f\bar{r}^2) / (1 - \bar{r}^2)$$

where $f = (1 - r_x) / [2(1 - \bar{r}^2)]$

$$\bar{r}^2 = (r_1^2 + r_2^2) / 2$$

Worked Example

Tritrac and fitness	r_1	=	0.659	z_{r_1}	=	0.791
Pedometer and fitness	r_2	=	0.593	z_{r_2}	=	0.682
Tritrac and pedometer	r_x	=	0.895			
N		=	27			

$$\bar{r}^2 = (0.659^2 + 0.593^2) / 2$$

$$= 0.393$$

$$f = (1 - 0.895) / [2(1 - 0.393)]$$

$$= 0.086$$

$$h = [1 - (0.086 \times 0.393)] / (1 - 0.393)$$

$$= 1.591$$

$$Z = (0.791 - 0.682) \{(27 - 3) / [2(1 - 0.895)1.591]\}^{0.5}$$

$$= 0.924$$

The two tailed P associated with a Z score of 0.924 is 0.358.

D4 CONTRASTS AMONG CORRELATED CORRELATION COEFFICIENTS

It was hypothesised that the activity monitors did a better job of predicting fitness and fatness of the children than did the commonly used measure of time spent with heart rate exceeding 139 bpm. Meng et al. (1992) showed the following method for testing contrasts among a set of correlated correlations.

$$Z = \sum \lambda_i z_{ri} \{ (N - 3) / [(\sum \lambda_i^2) (1 - r_x) h] \}^{0.5}$$

where λ_i 's = contrast weights assigned to each of the z_{ri} 's

z_{ri} 's = Fishers z for each predictor variable with dependent measure

r_x = median intercorrelation among the predictor variables being tested

h = as shown above (Appendix 4.3)

Worked example

Dependent variable	= fitness		
Predictor variable 1	= Sum Tritrac	Predictor variable 4	= Pedometer
Predictor variable 2	= \geq mod Tritrac	Predictor variable 5	= HR > 139bpm
Predictor variable 3	= \geq vig Tritrac		

Hypothesis: HR > 139 bpm predicts fitness less well than the average prediction obtained from the other four variables: Sum Tritrac; \geq mod Tritrac; \geq vig Tritrac; Pedometer

Contrast weights:	Sum Tritrac = 1	Pedometer = 1
	\geq mod Tritrac = 1	HR > 139 bpm = -4
	\geq vig Tritrac = 1	

The results from the one day analysis were used for all variables as only one day of data was available from heart rate.

Correlation matrix ($N = 20$)

Activity measure	Fitness (Y)	Sum Tritrac	\geq mod Tritrac	\geq vig Tritrac	Pedometer counts
Sum Tritrac (1)	0.532	—	—	—	—
\geq mod Tritrac (2)	0.470	0.827	—	—	—
\geq vig Tritrac (3)	0.343	0.731	0.803	—	—
Pedometer counts (4)	0.504	0.681	0.817	0.673	—
log HR > 139 (5)	0.077	0.341	0.370	0.568	0.207

$$\sum \lambda_{z_{ri}} = (1 \times 0.593) + (1 \times 0.510) + (1 \times 0.357) + (1 \times 0.555) + (-4 \times 0.064)$$

$$= 1.759$$

$$r_x = 0.677$$

$$h = 1.172$$

$$\sum \lambda_i^2 = (1)^2 + (1)^2 + (1)^2 + (1)^2 + (-4)^2$$

$$= 20$$

$$Z = 1.761 \{(20 - 3) / [20(1 - 0.677)1.172]\}^{0.5}$$

$$= 2.639$$

The two tailed P associated with a Z score of 2.639 is 0.008

Summary of Results

Dependent variable	N	$\sum \lambda_{z_{ri}}$	r_x	h	$\sum \lambda_i^2$	Z	P
Fitness	20	1.761	0.677	1.172	20	2.639	0.008
Fatness	22	-1.595	0.677	1.070	20	-2.644	0.008
Predictor variable 1	= Sum Tritrac		Predictor variable 4		= Pedometer		
Predictor variable 2	= \geq mod Tritrac		Predictor variable 5		= HR >139 bpm		
Predictor variable 3	= \geq vig Tritrac						

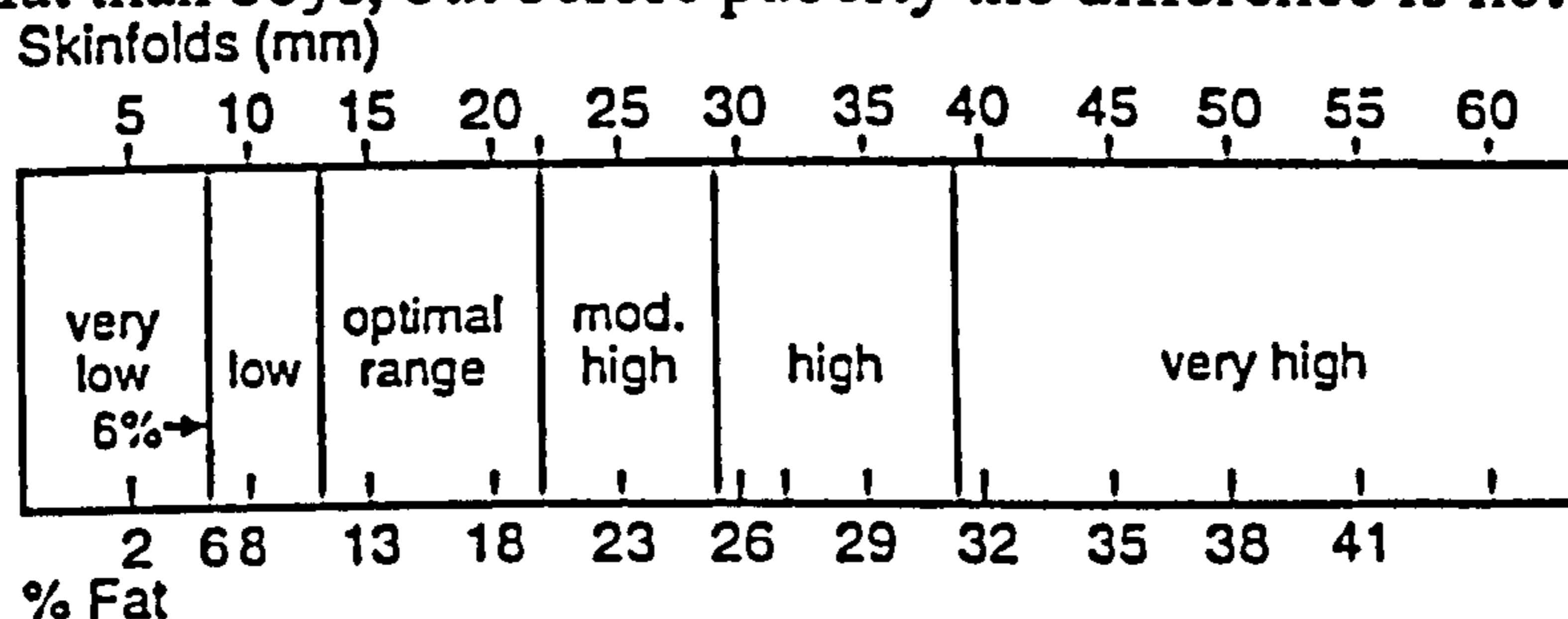
HR > 139 bpm does predict fitness and fatness significantly less well than the average of the four other predictions: Sum Tritrac; \geq mod Tritrac; \geq vig Tritrac; Pedometer.

D5 EXAMPLE OF FEEDBACK TO PARENTS

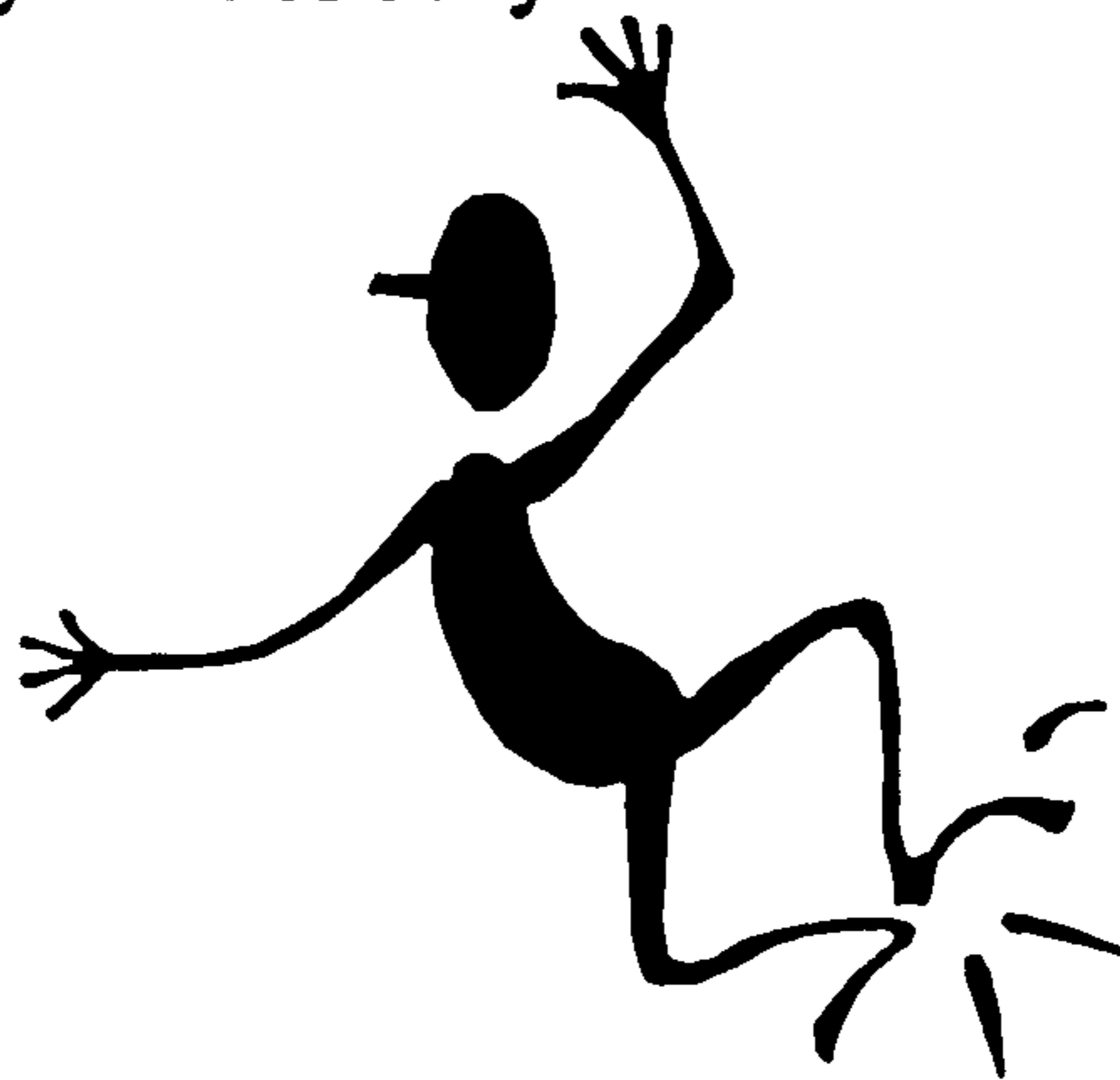
Ben
Autumn, 1997

Levels of body fat

Skinfolds provide an estimate of body fatness. This estimate is more accurate than only looking at body weight or a combination of weight and height. Girls carry more fat than boys, but before puberty the difference is not large.



The table above shows low, optimal (ideal) and high levels of body fat for boys. The table is based on the sum of two skinfolds, one from the back of the arm (triceps) and one from below the shoulder blade on the back (subscapular). For Ben the sum of these two skinfolds was 20.6 mm. As you can see he fits into the optimal range, this indicates a healthy level of body fat.



Levels of physical activity

The monitor that Ben wore tells us how many minutes he spent in moderate and vigorous activity on each day. Moderate activity is defined as equivalent to normal walking pace, vigorous activity is defined as equivalent to fast walking, running and jumping.

	minutes spent in moderate activity	minutes spent in vigorous activity or above
Tuesday	177	29
Wednesday	208	39
Thursday	133	39
Friday	159	33
Saturday	37	8
Sunday	180	22

It is recommended that children are physically active every day. Ideally children should spend 60 minutes in moderate to vigorous physical activity every day. For

teenagers and adults it is best to have twenty minutes of continuous vigorous exercise, though it is okay for children to accumulate this quantity through several sessions.

Aerobic fitness



The treadmill test that Ben did shows how aerobically fit he is compared to other boys his own age. The treadmill gets progressively steeper and faster with time. Ben was required to keep going for as long as possible, this takes a lot of motivation but Ben was up to the challenge. His time was 12 minutes and 33 seconds. The average time for a ten year old boy is 12 and a half minutes, Ben did better than approximately 50% of boys his own age would do. The enclosed photos show Ben during different stages of the test.

Once again, many thanks to you for taking part in this project. You are the most important people in our work, as without volunteers we cannot do anything.

Ann Rowlands



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Appendix E

Study 4: The relationship between body fatness and habitual physical activity in children: A meta-analysis

E1 Calculation of the effect sizes for studies included in the meta-analysis

E2 Comparison of effect sizes by activity measure

Appendix F

Assumptions of statistical tests

ASSUMPTIONS OF STATISTICAL TESTS

Based on Norušis (1997).

ANOVA

- The sample is representative of the population to which the inferences will be made.
- The dependent variable is measured on at least an ordinal scale.
- Independence: There is no relationship between observations within and between groups.
- Normality: The data is approximately normally distributed.
- Homogeneity of variance: The variances in the groups being tested are equal or nearly equal.

Testing these assumptions

Assumptions of normality can be tested by plotting a histogram for each of the groups.

Homogeneity of variance can be tested using Levene's test for equality of variance.

Regression

- The sample is representative of the population to which the inferences will be made.
- The variables are measured on at least an ordinal scale.
- The relationship is linear in the population.
- Each of the observations is independent. This assumption was violated in Studies 1 and 2 (Chapters 3 and 4). The implications of this are discussed in Appendix B2.
- For each value of the independent variable the distribution of the values of the dependent variable must be normal.
- The variance of the distribution of the dependent variables must be the same for all values of the independent variable - homoscedascity.

Multiple regression

In addition to the above:

- For every combination of values of the independent variables the distribution of the dependent variable must be normal and have constant variance.

Testing these assumptions

Residual = the difference between the observed and predicted values of the dependent variable.

ASSUMPTIONS OF STATISTICAL TESTS

Based on Norušis (1997).

ANOVA

- The sample is representative of the population to which the inferences will be made.
- The dependent variable is measured on at least an ordinal scale.
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- The variance of the distribution of the dependent variables must be the same for all values of the independent variable - homoscedascity.

Multiple regression

In addition to the above:

- For every combination of values of the independent variables the distribution of the dependent variable must be normal and have constant variance.

Testing these assumptions

Residual = the difference between the observed and predicted values of the dependent variable.

The residuals can be used to check whether the assumptions of independence, linearity and homoscedascity have been violated.

If the assumptions for regression analysis have been met

- The residuals should be approximately normally distributed.
- The variance of the residuals should be the same for all values of the independent variable.
- The residuals should be randomly scattered when plotted against the predicted values.
- Successive residuals should be approximately independent.

A scatterplot of the independent variable against the dependent variable will show if the data approximate a linear relationship.

To check for normal distribution a histogram of the residuals can be plotted.

A Q-Q plot of the standardized residuals can be used to check if a sample comes from a normal distribution. The points should fall in a reasonably straight line.

A plot of the standardized residuals against the predicted values can be used to check linearity and whether the variance of the dependent variable is the same for all values of the independent variable. The residuals should be randomly scattered around a horizontal line through zero. If the residuals are not randomly scattered about the line and curve instead this indicates non-linearity. If the residuals form a funnel shape this indicates heteroscedascity.

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