Does body mass index influence functional capacity in prepubescent children

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DOES BODY MASS INDEX INFLUENCE FUNCTIONAL CAPACITY IN PREPUBESCENT CHILDREN?

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Dedication

I dedicate this thesis to an exceptional woman, my mother, Pamela Riddiford.
Abstract

The proportion of overweight or obese children is steadily increasing. Despite this fact, virtually no research has been conducted to examine whether the functional capacity of these children is adversely affected by excess weight. The purpose of the present study was, therefore, to assess selected physical characteristics and functional capacities of prepubescent children to determine possible functional limitations experienced by obese children.

Four hundred and thirty one (boys = 212, girls = 219) Grade 3 students (mean age = 8.5 ± 0.5 years) from 18 randomly selected primary schools in the Wollongong District participated as subjects for this study. Subjects were required to progress through a circuit of stations designed to assess selected physical characteristics and functional capacities. Physical measures included height, body mass, lower limb alignment, and footprint structure. Functional tasks included a sit and reach test, upper limb static strength, a basketball throw, sit-to-stand transfers, a vertical jump and a standing long jump.

Body mass index (BMI) scores for all subjects were calculated and correlated to the performance scores on each of the functional tasks to establish the relationship between obesity and functional capacity. Data for 43 Obese subjects (BMI > 95th percentile for age and gender) and 43 Non-obese subjects (BMI at the 50th percentile for age and gender) were also compared to identify any significant differences (p < 0.05) between the obese and non-obese children with respect to the physical characteristics or functional capacity data.

Pearson Product moment correlations indicated that as BMI increased, flexibility, sit-to-stand transfer ability, vertical jump and standing long jump
performances and one footprint measurement (Chippaux-Smirak Index) significantly decreased. In contrast, upper limb static strength, basketball throw performances and the second footprint measurement (Footprint Angle) significantly increased with increasing BMI. Although significant, the correlations between BMI and functional performance were low (r ≤ 0.389) indicating that most of the variance in functional task performance could not be explained by its relationship with BMI.

When the Obese and Non-obese data were compared, sit-to-stand transfer ability, vertical jump and standing long jump performances and footprint measurements were significantly and negatively affected by obesity. In contrast, upper limb static strength and basketball throw performances were not limited by obesity and no differences were apparent in the lower limb alignment data between the Obese and Non-obese children.

It was concluded that when required to move their extra body mass against gravity, obese prepubescent children were at a functional disadvantage compared to children of normal body mass. As obesity was found to have a negative effect on children as young as 8 years of age when performing basic tasks, it is recommended that interventions should commence before this age.
Acknowledgements

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- All principals, staff, parents/guardians and particularly students of participating Wollongong District primary schools who gave so willingly of their time and themselves - a big thank you!
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- All postgraduate and undergraduate research assistants who gave their time in helping to collect data in the school settings - quite an effort!
- Dr. Louise Baur for her continued interest and input.
- Mr. Mario Solitro for his assistance in constructing the adjustable platform and the static strength tester.
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Finally, I would like to thank my husband, Martin, for his unselfish sharing of knowledge, his ability to remain calm, and his faith in me. And of course, thanks must go to my family who had no choice but to help, yet never let me down - thank you.
Publications

The following publications and presentations have arisen directly from the work conducted for this thesis.

Papers


Conference Presentations


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Chapter 1

The Problem

1.1 Introduction

All bodily activities require energy. This need for energy is met by consuming food that contains energy in chemical form. If the body is to function efficiently, an appropriate amount of energy must be consumed to counteract energy expenditure. Maintaining an energy balance, so that energy input equals energy output, is vital for a person's health and well-being. When there is a constant bias over time so that energy input exceeds energy expenditure, body fat stores become excessive, causing obesity (Poskitt, 1994; Lester, 1994; Epstein, 1995; Flatt, 1995).

The incidence of obesity has steadily increased over the last four decades in industrialised society (see Section 2.1). It is now considered a major health hazard, causing impaired quality of life (English & Bennett, 1985; Kral et al., 1992; Blundell & Bauer, 1994; Seidell, 1995). If obesity is allowed to continue unchecked until body weight far exceeds recommended levels, numerous chronic disorders may develop including: circulatory diseases, cancer, non-insulin dependent diabetes mellitus, hypertension, respiratory diseases and musculoskeletal disorders (Garrow, 1991; ABS, 1992; Rice et al., 1995). For example, obesity has been found to be associated with the onset of musculoskeletal disorders such as osteoarthritis.

Osteoarthritis is a chronic, degenerative disease of the joint cartilage that causes pain and movement restriction (White-O'Connor et al., 1989). The association between obesity and osteoarthritis is thought to be due to increased stress on weight-bearing structures of the body caused by increased body weight (Hartz et al., 1986; Anderson & Felson, 1988; Carline, 1996). Joint pain caused by osteoarthritis may limit physical activity, thus, perpetuating an increase in obesity. Absolute excess in body weight, or morbid obesity, can also restrict an individual's
involvement in certain physical, social and emotional endeavours (Stewart & Brook, 1983), again compounding problems associated with obesity.

While numerous studies have suggested an association between increased obesity and declines in both psychological and physiological health status, few have investigated functional restrictions experienced by obese subjects (Kral, 1985; Revicki, 1990). The few studies that have examined the effects of obesity on functional ability during activities of daily living (ADL) have administered self-reporting questionnaires to collect data. However, an inherent problem associated with data obtained by such self-assessment is reduced accuracy due to the subjective responses provided by subjects and problems with subject recall (Wing et al., 1979). Despite these limitations, a direct relationship has been found between increased severity in obesity during adulthood and a subject's inability to perform ADL (Must et al., 1992; Ensurud et al., 1994; Galanos et al., 1994). However, no research was located to identify at what age obesity impaired performance or the effects of obesity in childhood on the performance of ADL. Therefore, it is unknown if obese children are physically restricted in their daily lives and, if so, how.

Recent literature pertaining to childhood obesity has suggested a positive correlation between child and adult obesity (Whitaker et al., 1997; Barker, 1999). That is, obese children tend to become obese adults who subsequently experience the chronic disorders associated with the disease as described previously. Although it is thought that childhood obesity becomes evident during prepubescence (Davies et al., 1995; McMurray et al., 1995), it is not known at what point in maturation obesity has a negative influence on physical performance.

Restrictive pathological musculoskeletal conditions which obese children have been documented to incur, include tibia vara* and slipped capital femoral epiphysis**. Both conditions affect lower limb functionality, causing deformity or injury, and are

* bowing of the leg toward the midline of the body (Miller & Keane, 1978).
** weakening of the proximal femoral growth plate causing separation of the femoral head and neck (Eilert, 1987).
commonly seen in childhood or adolescence. Continual excessive weight-bearing seems a prerequisite for these disorders to occur (Rab, 1983; Pritchett & Perdue, 1988; Cook et al., 1993; Henderson & Greene, 1994). The consequence of restricted physical activity caused by the lower limb malpostures associated with these conditions only serves to perpetuate a decrease in energy expenditure and, in turn, an increase in obesity. Although physical restrictions associated with specific lower limb pathologies such as tibia vara and slipped epiphysis are documented, no studies were located examining the effects of excess body weight (without specific pathologies) on musculoskeletal functional capacity. Therefore, it is unknown if functional capacity, particularly musculoskeletal functional capacity of the lower limbs, is negatively affected in children as a consequence of supporting excess body mass.

1.2 Purpose of the Study

The purpose of this study was to determine the effect of obesity on functional capacity, particularly musculoskeletal functional capacity of the lower limbs, in prepubescent children. This was investigated by correlating body mass index values calculated for prepubescent children to their performance scores achieved during a series of functional tasks (see Section 2.3). The performance achieved by obese and non-obese children on the same functional tasks was also compared.

1.3 Research Hypotheses

Based on a review of literature pertaining to obesity it was hypothesised that:

1) An increase in obesity would be associated with a decrease in:
   a) flexibility during forward trunk flexion,
   b) lower limb strength and power, and
   c) the ability to perform a functional task such as a sit-to-stand transfer.

2) An increase in obesity would be associated with no change in upper limb strength and power displayed during functional tasks.

3) An increase in obesity would be associated with an increase in:
   a) deviation into tibial varus, and
   b) the surface area of the foot contacting the ground.
1.4 Significance of the Study

Despite a comprehensive review of the literature, no information was found which adequately assessed the effects of excessive body mass on the functional capacity of prepubescent children. Therefore, the main aim of this study was to determine whether obese children were physically restricted in performing functional tasks. Knowledge of such restrictions is vital in order to design and implement appropriate intervention strategies to assist in preventing problems associated with childhood obesity, problems which may be exacerbated even further during later life if excessive weight gain continues.

Apart from reducing emotional, social and health-related problems, a decrease in obesity and its associated disorders would have significant economic benefits to the community. According to the National Health and Medical Research Council (NHMRC) the direct cost of obesity in 1992-1993 to the Australian healthcare system was over $500 million. Including indirect costs, this value was estimated to exceed $800 million. Furthermore, the estimated cost of weight loss programs, a category not included in indirect costs, exceeded $500 million per year. Therefore, urgent research is warranted to identify factors which may be used to reduce the impact of obesity within society.

1.5 Limitations and Delimitations

1.5.1 Limitations

The results of this study were limited by the following factors:

1) Only children for whom school Principal, parental/guardian and individual consent had been provided participated in the study. Therefore, the sample was not truly random.

2) Although all testing was conducted within school hours (9:00am - 3:00pm) results may have varied among children due to differences in the time of day the assessments were conducted, whether children had eaten before assessment, activities children may have been involved in before assessment, and the children's level of motivation.
3) Although all instructions were designed considering the cognitive development of prepubescent children, the variation in level of comprehension of task requirements may have influenced performance.

4) Despite familiarising the children with each protocol, children may have altered the way they typically performed a task because they were aware they were being assessed.

1.5.2 Delimitations

Limitations imposed on the present study included:

1) Analysis of functional ability was restricted to students with no identifiable physical and/or medical conditions, apart from obesity, which may have influenced functional performance.

Other limitations and delimitations that may have influenced the study results are described within the body of the thesis.

1.6 Definitions

Abbreviations used within the text of the thesis are defined in Table 1.1 whereas a glossary of terms are included in Table 1.2. Abbreviations, notations and symbols used in tables or equations are defined within the relevant table or equation.
### Table 1.1 Abbreviations used within this thesis.

<table>
<thead>
<tr>
<th>Notation</th>
<th>Definition</th>
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<tr>
<td>AAHPERD</td>
<td>American Alliance for Health, Physical Education, Recreation and Dance</td>
</tr>
<tr>
<td>ABS</td>
<td>Australian Bureau of Statistics</td>
</tr>
<tr>
<td>ACHPER</td>
<td>Australian Council for Health, Physical Education and Recreation</td>
</tr>
<tr>
<td>ADL</td>
<td>activities of daily living</td>
</tr>
<tr>
<td>BMI</td>
<td>body mass index</td>
</tr>
<tr>
<td>BT</td>
<td>basketball throw</td>
</tr>
<tr>
<td>CSI</td>
<td>Chippaux Smirak Index</td>
</tr>
<tr>
<td>FA</td>
<td>Footprint Angle</td>
</tr>
<tr>
<td>ICC</td>
<td>intraclass correlation coefficient</td>
</tr>
<tr>
<td>NHMRC</td>
<td>National Health and Medical Research Council</td>
</tr>
<tr>
<td>ROM</td>
<td>range of motion</td>
</tr>
<tr>
<td>S&amp;R</td>
<td>sit and reach test</td>
</tr>
<tr>
<td>SCM</td>
<td>standing calcaneal measurement</td>
</tr>
<tr>
<td>SLJ</td>
<td>standing long jump</td>
</tr>
<tr>
<td>STM</td>
<td>standing tibial measurement</td>
</tr>
<tr>
<td>STS</td>
<td>sit-to-stand</td>
</tr>
<tr>
<td>VJ</td>
<td>vertical jump</td>
</tr>
<tr>
<td>VLH</td>
<td>vertical line through the hip</td>
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<tr>
<td>WHO</td>
<td>World Health Organisation</td>
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### Table 1.2 Glossary of terms used within this thesis.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Activities of daily living</td>
<td>physical activities typically performed during a normal day, such as walking, running, sitting, standing, carrying, and lifting</td>
</tr>
<tr>
<td>Functional capacity</td>
<td>the capacity to perform activities of daily living</td>
</tr>
<tr>
<td>Functional tasks</td>
<td>tasks designed to assess an individual’s functional capacity</td>
</tr>
</tbody>
</table>
Chapter 2

Literature Review

In order to examine the effects of obesity on functional capacity it was necessary to develop a general understanding of problems associated with obesity, effects of obesity on functional capacity and methods to assess obesity and functional capacity. Therefore, relevant literature in the following areas has been reviewed:

1) Obesity and Body Mass Index
2) Effects of Obesity on Functional Capacity
3) Assessment of Functional Capacity

2.1 Obesity and Body Mass Index

There is considerable literature documenting the increase in the prevalence of obesity in affluent countries (Zimmet, et al., 1986; Stamler, 1993; James, 1995). In Australia, data compiled by Bennett & Magnus (1994) from the 1980-1989 National Heart Foundation studies indicated that in 1980, 9.3% and 8.0% of adult males and females, respectively, were obese. In only nine years these figures had escalated to 11.5% for males and 13.2% for females. Similarly, the number of obese children has also risen (Seidell, 1999). Lancashire (1997) cited a study conducted by the National Health Statistics (Maryland, USA) which indicated that from 1976-1980 to 1988-1994 the percentage of obese children aged between 6 and 11 years had almost doubled from 7.6% to 13.7%. In 1992, it was estimated that 15% of Australian children 5 to 11 years of age were obese (Baur, 1995). As obesity in childhood is thought to lead to adult obesity (Davies et al., 1995; Steinbeck, 1996; Whitaker et al., 1997), factors affecting childhood obesity warrant further investigation.

While a standard, agreed measurement of obesity remains to be formulated (Rolland-Cachera, 1999) the most common measure of obesity is body mass index (BMI; Ruggiero & Clark, 1992; Stamler, 1993; Wilmore 1994; NHMRC, 1996).
BMI is calculated using the formula:

\[ \text{BMI} = \frac{\text{mass}}{\text{height}^2} \]  

Equation 2.1

where: \( \text{BMI} \) = body mass index (kg/m\(^2\))

mass = body mass (kg)

height = stature (m)

More sophisticated techniques available for assessing body composition include hydrostatic weighing, bioelectrical impedance and dual energy X-ray absorptiometry. A detailed account of these methods can be found in Lukaski (1987), Heyward (1989), Kehisa et al. (1994) and Rothacker (1995). Although more accurate in quantifying obesity than BMI, these more sophisticated techniques are often not viable for studies that include large sample sizes and/or are conducted in the field due to both cost and time restrictions. Skinfold measurements, girth measurements, hip-to-waist ratios, weight and height indices (weight/height, weight/height\(^2\), and weight/height\(^3\)) and growth percentiles have therefore been developed as relatively practical and valid methods for assessing body size (Watson et al., 1979; Lohman, 1981; Rolland-Cachera et al., 1982). However, these measures must be used cautiously and the results must be compared within specific populations due to established cultural variations in body structure and composition. As many of these measures make generalised assumptions about fat distribution, they may not, for example, distinguish people whose weight is predominantly lean muscle mass (Lukaski, 1987; Richelsen & Pedersen, 1995; NHMRC, 1996).

The NHMRC until recently, classified underweight, acceptable weight, overweight and obesity in Australian adults using a range of BMI scores where a score above 30 typically indicated obesity (NHMRC, 1996). However, the World Health Organisation (WHO) has suggested variation to these scores, with an Expert Committee (1995) recommending the classifications listed in Table 2.1.
Table 2.1  Classifications of Body Mass Index for adults (WHO, 1995, p 452).

<table>
<thead>
<tr>
<th>Classification</th>
<th>BMI</th>
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<tr>
<td>Normal range</td>
<td>18.50 ≥ BMI &lt; 25.00</td>
</tr>
<tr>
<td>Grade 1 overweight</td>
<td>25.00 ≥ BMI &lt; 30.00</td>
</tr>
<tr>
<td>Grade 2 overweight</td>
<td>30.00 ≥ BMI &lt; 40.00</td>
</tr>
<tr>
<td>Grade 3 overweight</td>
<td>BMI ≥ 40.00</td>
</tr>
</tbody>
</table>

For children, BMI percentile charts based on chronological age are considered more appropriate to classify obesity rather than comparing child data to adult classifications due to the effects of developmental stages of maturation on body weight and height (Power et al., 1997; Rolland-Cachera, 1999). On such percentile charts a BMI score above the 95th percentile commonly classifies a child as obese (Hammer et al., 1991; Baur, personal communication, October, 1995; Seidell, 1999). Percentile charts for both boys and girls are included in Appendix A.

2.2 Effects of Obesity on Functional Capacity

Research into obesity has predominantly focussed on biochemical factors associated with the aetiology of this disease and prevention of its occurrence. Human and animal studies have investigated, for example, leptin and insulin sensitivity, metabolic control and dietary feeding habits (Storlien & Bruce, 1989; Huang et al., 1996; Storlien & Jenkins, 1996; Baur et al., 1998; O’Rahilly, 1998). Pharmacological and surgical intervention, as a means of controlling obesity, have also been examined in detail (Hawke et al., 1990; Kral et al., 1992; O’Brien, 1994).

An underlying assumption common to these studies is that limitations experienced by obese people restrict their ability to function efficiently, both psychologically and physically, in their daily lives. However, the assumption that obesity causes a reduction in functional capacity to impair an obese individual’s quality of life has, as yet, not been objectively established.

Only a few studies were located that systematically and prospectively investigated the effects of obesity on an individual’s ability to perform functional tasks (Keil et
al., 1989). However, most of these studies relied on self-reporting questionnaire responses and hence were limited by the inherent problems associated with such questionnaires (see Section 1.1). Despite these limitations, a follow up study conducted over 13 years by Must et al. (1992) compared the effects of adolescent obesity on mortality and morbidity. The authors concluded that women who were overweight adolescents were eight times more susceptible to experiencing 'difficulty with personal care and routine needs in the activities of daily living' than their lean counterparts (p. 1352).

Unfortunately to date, controlled quantitative analyses of the effect of obesity on functional capacity during ADL has been restricted to the analysis of locomotion (Hills & Parker, 1991; Sypropoulos et al., 1991; Hills & Parker, 1993; Messier et al., 1994). The gait of obese adults has been characterised by a slow and tentative progression compared to normal weight peers. Whereas obese subjects adhered to the normal pattern of locomotion, differences in gait parameters between obese and non-obese subjects were evident. These differences included a shorter and wider stride, longer gait cycle, more time spent in stance phase and a greater degree of toe out displayed by obese subjects compared to non-obese controls (Hills & Parker, 1991; Sypropoulos et al., 1991; Messier et al., 1994). Hills & Parker (1993) hypothesised that increased demands would be placed on the lower limb musculature of obese children compared to their non-obese counterparts due to the need to bear additional weight. The hypothesis was subsequently examined by evaluating lower limb muscle activation patterns of obese children during three speeds of walking compared to their lean counterparts. Although no significant differences in electromyographic activity were found between the obese and non-obese children, the authors indicated the probable effects of excess weight carriage warranted further investigation due to limitations with their experimental procedures. Procedures suggested for further research included examining an increased walking distance (that is, more than 10 m) and a larger sample size which included a greater range of weight and age groups. No other published research was located which investigated the functional capacity of obese children performing ADL.
Although not specific to obesity, a related area of investigation has been the effect of additional mass induced by external load-carrying on human performance. Whereas most of these studies have again focussed on assessing physiological effects of external load carrying (Soule et al., 1978; Pimental & Pandolf, 1979; Bobet & Norman, 1984; Myo-Thein et al., 1985), only limited research has examined the biomechanical effects of external loads (Martin & Nelson, 1986) on mechanical efficiency. For example, in a study examining the effects of two pack systems of differing mass on walking efficiency, Kinoshita (1985) found that an increase of 40% body weight for experienced backpackers and 20% body weight for inexperienced carriers resulted in impaired biomechanical efficiency in walking. This impairment was characterised by changes in fundamental gait parameters which included altered joint angles, changes in segmental orientations, shorter step width and greater time spent in double support phase. Further research confirmed this impairment, showing that an increase beyond one-third of body weight significantly affected walking performance (Haisman, 1988) and that the average loss of performance was 1% per kilogram mass increase (Holewijn & Lotens, 1992). Therefore, it is apparent that the need to carry excess mass can lead to significant reductions in functional performance of fundamental ADL such as walking. It should be noted, however, that these studies pertaining to load-carryage were restricted to adults and, in particular, to military personnel. No similar studies were located which examined the effects of external load-carryage on the functional capacity of children.

2.3 Assessment of Functional Capacity

The terms functional capacity, functional capability (or ability) and functional status have been commonly associated with studies of the elderly (Aniansson et al., 1980; Donaldson & Jagger, 1983; Lindmark, 1988; Anttila, 1991; Wolinsky et al., 1993). For example, Galanos et al. (1994) claimed measures of function or functional capabilities could be assessed by documenting the ease at which functional tasks, such as ADL and mobility, could be performed. In contrast, in studies involving younger populations, particularly children, these terms have been used to describe the assessment of aerobic power or oxygen uptake rather than documenting the
efficiency by which ADL were performed (Sprynarova, 1974; McArdle et al., 1991; Eggar & Champion, 1993). No research was located which assessed functional capacity of children, where functional capacity was defined according to the definition that was adopted in the present study, that is, as possessing the necessary functional abilities required to successfully execute ADL.

To successfully participate in ADL and recreation requires adequate flexibility and muscular functionality, and appropriate musculoskeletal structure and alignment (Haskell et al., 1985). The more an individual possesses these functional capacities, the lesser the risk of musculoskeletal fatigue or injury (Weltman, 1989; Gaul, 1996) and the more efficiently ADL can be performed.

2.3.1 Flexibility

Flexibility is a measure of the range of motion (ROM) possible at a joint (Hubley, 1991). Most joints are comprised of bone, articular cartilage, ligaments and a joint capsule that are surrounded by other soft tissue structures such as muscles and tendons. The interaction among these components determines motion available at a joint, where certain bone configurations and tissue restrictions limit the possible ROM (Nordin & Levangie, 1992). Typically, a joint with a greater ROM (within normal limits) is advantageous in terms of aiding both efficient motor performance and injury prevention as compared to a restricted joint (Alter, 1996; Whiting & Zernicke, 1998). The acquisition and maintenance of an increased ROM occurs with frequent use of the joint through an appropriate ROM combined with sufficient strength and coordination of the necessary musculature so that the joint remains supple and capable of performing required movements (Kreigbaum & Barthels, 1996). A decrease in ROM can occur as a result of inactivity and aging. In such cases both habitual inactivity and the aging process, and/or the constant maintenance of an inappropriate posture or stance, may lead to a shortening or tightening of connective tissue, thus limiting possible movement (Heyward, 1989). Range of motion is also affected by the contact of adjacent tissue masses surrounding the joint. For example, extreme muscle bulk or adipose tissue will
interfere with normal movement and thereby decrease ROM (Kreigbaum & Barthels, 1996; Whiting & Zernicke, 1998). A combination of excess adiposity and inactivity will therefore have a two-fold effect on reducing ROM, both by premature tissue contact and by muscle and other connective tissue changes associated with inactivity.

Apart from body mass and inactivity, other factors that may affect ROM include age and gender. After approximately 5 to 6 years of age, flexibility begins to decline, with females usually being more supple than males (DiNucci, 1976; Branta et al., 1984; Gabbard & Tandy, 1988). The rate of decline will be influenced by the amount and type of daily physical activity an individual performs and the size and shape of the individual. Krahenbuhl & Martin (1977) investigated the relationship between body size and flexibility of children aged 10 to 14 years. The authors assessed upper and lower limb joint flexibility and concluded that as body surface area increased, knee, hip and shoulder flexibility scores decreased. In contrast, Gabbard & Tandy (1988) found no correlation between body composition and flexibility of 5 and 6 years olds. However, these authors concluded that skinfold measures, used to determine body fat in their study, were not suitable to assess a relationship between body composition and flexibility. A further limitation of this study was that subjects had a mean BMI of between 15 and 16 and therefore did not include obese children.

Flexibility is frequently included as a component of physical fitness and health-related assessment, particularly when assessing children and adolescents (Galley & Forster, 1982; American Alliance for Health, Physical Education, Recreation and Dance (AAHPERD), 1984; Ross & Pate, 1987; Barkauskas, et al., 1994; Safrit, 1995; Docherty, 1996). As ROM is joint specific, total body joint motion can not be measured using a single test score for one joint (Shephard et al., 1990). Consequently, many tests have been devised to assess the ROM about various joints and the extensibility of various muscles within the musculoskeletal system (Leighton, 1955; Munroe & Romance, 1975).
Sit and Reach Test: One test which assesses flexibility* across several joints is the sit and reach (S&R) test. Traditionally, the S&R test was considered a valid measure of both lower back flexibility and hamstring extensibility (Wells & Dillon, 1952). However, Jackson & Baker (1986) and Jackson & Langford (1989) suggested that, whereas the S&R test adequately assessed hamstring extensibility, it was a poor indicator of lower back flexibility. A limitation of the S&R test as an indicator of lower back flexibility was proposed as early as 1954 by McCloy & Young and again by Broer & Galles in 1958. Based on studies completed by these authors, it was concluded that persons with extreme body proportions were either at an advantage or disadvantage in performing the test, whereas the performance of persons of average build was not significantly affected. In contrast, Mathews et al. (1957) and Feildman (1967) found no significant relationship between segmental lengths and performance on the S&R test. Jackson & Baker (1986) suggested that as only a few subjects would fall into the category of extreme body types, the test remained a valid measure of hamstring extensibility. Furthermore, the S&R test can be used as a measure of the degree of ‘forward flexion of the trunk rather than the ROM from full flexion to full extension’ (Docherty, 1996, p. 295). Such a test can therefore be used to indicate how successfully a person can reach towards their toes: a task to assess a functional capacity (Sinclair & Tester, 1993). For this reason, the S&R test remains one of the most commonly used tools for assessing flexibility in children (Ross & Pate, 1987; Safrit, 1995; ACHPER, 1995).

Numerous fitness surveys have provided normative data for the S&R test performed by prepubescent children (AAHPERD, 1980; Pyke, 1985; National Children and Youth Fitness Study II (NCYFS II), 1987; Ross et al., 1987). From such data it has been shown that boys and girls aged 8 years (n = 986) reached a mean distance of 2.4 ± 5.3 cm and 5.8 ± 5.2 cm, respectively. Of the 969, 9-year-old subjects, boys recorded a mean distance of 1.3 ± 5.6 cm, whereas the girls

* The terms flexibility and extensibility are often used to describe the same movement capacity. However, flexibility refers to the ROM permitted at a joint whereas extensibility refers to the ROM of the joint connective tissue, in particular the musculature (Alter, 1996). In the present study, by convention, flexibility has been used to identify the ability of the muscles and connective tissue surrounding a joint to lengthen to allow joint ROM.
recorded a mean distance of $5.3 \pm 6.2$ cm (Pyke, 1985). Only one study was located which examined the flexibility of obese children. Pongprapai *et al.* (1994) compared the fitness of Thai children (mean age = 9.2 years). The authors concluded that there were no differences in the S&R distance of normal weight (boys: $1.9 \pm 5.7$ cm; girls: $1.6 \pm 5.6$ cm), overweight (boys: $1.4 \pm 4.7$, girls: $3.3 \pm 4.0$ cm) and obese (boys: $0.1 \pm 6.3$; girls: $1.9 \pm 5.1$ cm) children. However, no research was located examining the effects of obesity on S&R test performance in Australian children.

### 2.3.2 Strength and Power

Strength and power are terms pertaining to muscular functionality that are often used synonymously, although they do not refer to the same ability (Kreighbaum & Barthels, 1996). Strength refers to the ability of a muscle to produce force against a resistance whereas power is the rate at which the force can be developed (Knuttgen & Komi, 1986; Gaul, 1996). Strength and power are basic requirements for normal human motion with skeletal muscle weakness resulting in impaired motor function (Davis & Isaacs, 1983; Rupnow, 1985; Hinson, 1995). To identify functional muscular strength (or weakness), Amundsen (1990) recommended that the performance of ADL, such as sitting up from a supine position, standing from a sitting position and stair climbing should initially be assessed. Furthermore, Sargeant (1989) claimed that measuring muscle power output provided a relevant indication of functional capacity in children. Activities such as throwing, jumping and striking all require the ability to produce force during a high velocity movement and therefore require explosive power (Newton & Kraemer, 1994). A combination of both strength and power tasks should therefore be incorporated to effectively assess functional capacity.

Several tests have been developed as valid measures of lower and upper limb strength and/or power including manual muscle testing, isometric and isokinetic muscle testing, and dynamometry (Sunnegardh *et al.*, 1988; Heyward, 1989; Amundsen, 1990; Sale, 1991). However, many of these tests require elaborate and
expensive equipment designed for adult segmental dimensions and are consequently inappropriate for testing children or large subject numbers in the field. Furthermore, many of the tests are specific to a muscle or muscle group involved in a particular test motion, and therefore cannot be used to assess strength and power requirements of functional tasks. Tests that have been advocated as appropriate to assess functional lower and upper limb muscular strength and power of children in the field are discussed below.

**Lower Limb Strength and Power Assessment**

**Vertical Jump Test:** The vertical jump (VJ) protocol, as described by Kraemer & Newton (1994), is an effective measure of lower limb power which is inexpensive and easy to administer in the field (Branta, 1984; Weltman et al., 1986; Davies, 1990; Roebuck, 1995). Lower limb power is determined in the test by measuring the height reached by the subject after jumping vertically from a static position. The height reached is dependent on jumping style (Brancazio, 1984). It is pertinent, therefore, to adhere to a standard assessment protocol so that no confounding factors, such as the use of arm swing to increase momentum or counter movements, influence the height jumped (Harman et al., 1990; Sargeant, 1993). Vertical jumping ability of prepubescent boys and girls, employing the protocol of Kraemer & Newton (1994), has been assessed in several studies (Hensley et al., 1982; Branta et al., 1984; Jensen, et al., 1994). For example, Branta et al. (1984) reported that boys (aged 8 years and 9 years) were observed to reach mean heights of $9.79 \pm 1.97$ inches ($\approx 24.9 \pm 4.6$ cm) and $10.47 \pm 1.6$ inches ($\approx 26.6 \pm 4.1$ cm), respectively, whereas 8- and 9-year-old girls jumped $9.30 \pm 1.80$ inches ($\approx 23.6 \pm 4.6$ cm) and $10.39 \pm 1.59$ inches ($\approx 26.4 \pm 4.0$ cm), respectively.

Body mass will also influence the resultant vertical jump score because participants with a large body mass are disadvantaged by the need to apply a greater force to accelerate their larger mass a given distance (Brancazio, 1984). In overweight and obese individuals, their larger mass, although accompanied by an increase in lean muscle mass (Forbes & Welle, 1983; Jonston, 1985; Bandini & Dietz, 1987), is predominantly caused by excess adiposity (Blimkie, 1989; Malina, et al., 1995;
Simoneau & Kelley, 1999). Unlike lean tissue, adipose tissue does not contribute to force generation (Astrand & Rodahl, 1977). Even with increased lean tissue, therefore, obese individuals may still be at a disadvantage in VJ tests due to the adverse effect of a larger percentage of body fat compared to lean mass.

**Standing Long Jump Test:** The standing long jump (SLJ) or standing broad jump is another method used to assess leg power (Toriola, 1986; Kozlowski, 1988; Davies, 1990; Izquierdo et al., 1993). In this test the maximum horizontal distance that the subject’s body is displaced is indicative of lower limb power. From a stationary position, feet parallel behind a designated mark, subjects are required to jump as far forward as possible, landing with feet together. The use of arm swing for propulsion during SLJ has been incorporated into various fitness tests (Pyke, 1985; Safrit, 1995; Aguado et al., 1997). As this action requires a certain degree of coordination, particularly in prepubescent children (Branta et al., 1984), the SLJ performed with minimal or no arm movement is considered a more accurate indication of lower limb power. No studies, however, were located in which arm action was controlled during assessment of prepubescent children performing a SLJ. Previously recorded data for the SLJ performed by prepubescent boys and girls, therefore, must be interpreted cautiously as the scores may have been influenced by inconsistent use of arm swing. Considering this limitation, the Australian Health and Fitness Survey (Pyke, 1985) reported that 8-year-old boys jumped a mean horizontal distance of 126.3 ± 18.2 cm, 9-year-old boys jumped 135.1 ± 19.1 cm, 8-year-old girls jumped 119.2 ± 18.1 cm and 9-year-old girls jumped 127.4 ± 18.7 cm.

Similar to the VJ, body mass has been identified as a critical influential factor in performing the SLJ (Malina, 1988; Suzuki et al., 1993; Docherty, 1996). According to Hensley et al. (1982), body fatness appeared to have a detrimental effect on motor performance in tasks that required moving the total body mass; a finding previously expressed by Slaughter et al. (1977; 1980). The magnitude of this relationship was not defined and consequently further experimental research
was recommended to define the effect of body mass on SLJ performance (Hensley et al., 1982).

**Sit-to-Stand Transfer:** Rising from a sitting position is an activity performed many times every day. For example, McLeod (1975) stated that adults (aged 23 to 41 years) rose an average 90 times daily. To complete this task successfully requires adequate lower limb muscular strength (Kelley et al., 1976; Burdett et al., 1985; Arborelius et al., 1992; Gross, 1993; Hughes, 1994; Roebroeck et al., 1994). Consequently, sit-to-stand (STS) transfers are often used as an indicator of functional lower limb strength (see Figure 2.3.2). In young healthy persons this activity should be achieved with ease, whereas the elderly or disabled may experience difficulty as indicated by an increased time to rise, the need to reposition the body segments to rise and the inability to rise from low chair heights (Munton et al., 1981; Kerr et al., 1991; Wretenberg & Arborelius 1994; Baer & Ashburn, 1995).

![Figure 2.1](image.png)  
**Figure 2.1** The sit-to-stand transfer procedure for a healthy young adult (Kerr et al., 1997, p 238).

Biomechanical analyses of the STS motion have generally focussed on the performance of either healthy adults (Kelley et al., 1976; Naumann et al., 1982; Fleckenstein et al., 1988; Rodosky et al., 1989; Schenkman et al., 1990; Kralj et al., 1991; Pai & Rogers, 1991; Hutchinson et al., 1994) or elderly and/or impaired persons (Burdett et al., 1985; Millington et al., 1992; Schltz et al., 1992; Hughes et al., 1994; Baer et al., 1995; Lundin et al., 1995) with little research examining how children perform this task (Riley et al., 1991; Cahill et al., 1999). Analyses have focussed on both the kinetics and kinematics of standing in an attempt to define
strategies employed by adults to rise successfully (Wheeler et al., 1985; Millington et al., 1992; Hughes et al., 1994). Variables displayed during STS transfers such as joint angles, muscle activity, ground reaction forces and joint forces (torques and moments) all have been extensively researched (Ellis et al., 1984; Fleckenstein et al., 1988; Kerr et al., 1991; Kralj et al., 1991). The effect of numerous constraints on STS performance, including seat height, arm usage, body position, and temporal aspects of rising have also been investigated (Burdett et al., 1985; Rodosky et al., 1989; Wretenberg et al., 1993; Coghlin & McFadyen, 1994; Roebroeck et al., 1994; Munro et al., 1998). From these studies it was agreed that as chair height was increased, and arm use allowed, a subsequent decrease in muscle activity, joint and muscle forces was observed. Therefore, STS transfers performed from low seat heights and without arm motion require greater lower limb strength, thereby providing a functional assessment of lower limb strength, compared to those performed from a standard chair and using arm action. However, no research was located which assessed lower limb strength in children using a STS transfer or of the effects of obesity on performing this task.

Upper Limb Strength and Power Assessment

Similar to lower limb assessment, strength and power of upper limb musculature are components of physical fitness frequently assessed in health-related tests. Test items traditionally used to assess upper limb strength and/or power include; push-ups, pull-ups, flexed arm hang, bench presses, arm curls, push/pull and grip strength tests (Metheny, 1941; Heebøll-Nielson, 1982; Jette et al., 1989; Saffit, 1995; Docherty, 1996). Pate and associates (1993), however, suggested that the validity of such tests in children remained undocumented. Furthermore, performance on the pull-up test, for example, seems to be ‘confounded by body weight, which constitutes the resistance overcome in performing [this test]’ (Pate et al. 1993, p. 17). Cotton (1990), Flosom-Meek et al. (1992) and Docherty (1996) also concluded that children often obtained zero scores on particular upper limb strength test items because of an inability to support body mass. Flosom-Meek et al. (1992), in a study of 104 children (Grade 1 to Grade 6), found that children with high percentages of body fat experienced difficulty completing the tasks used to
assess upper limb strength which included pull-up and chin-up tests. Modified tests have therefore been designed to assess upper limb strength so that the need for subjects to lift their entire body mass is removed. Cotton (1990) analysed one such modified pull-up test included in the National Children and Youth Fitness Study II (1987). Test scores of 171 boys and 192 girls from Kindergarten to Grade 6 on this modified test were significantly negatively correlated with body mass, suggesting that the heavier children still recorded lower scores when trying to move their body mass. Cotton (1990) concluded that, although superior (that is, there were virtually no zero scores) to the traditional pull-up and flexed-arm-hang tests, the validity of the modified pull-up test remained questionable. The modified push-up test developed by Nelson et al. (1991) indicated a ‘significant degree of validity and reliability and can be used as a functional test of upper body strength’ (Nelson et al., 1991, p. 441). However, the effects of increased body mass on test results have not been investigated. Unlike the lower limbs, the upper limbs are rarely used to support body mass during ADL. Therefore, tests which assess upper limb muscle strength and power and which do not involve children supporting their body mass are considered more relevant from a functional perspective. Non-weight bearing tests designed to assess upper limb strength and power are therefore reviewed in the following section.

Upper Limb Static Strength Test: Field assessments of upper limb static strength have used operator hand-held (Bohannon, 1990) and subject hand-held push/pull (Jette et al., 1989) dynamometers. Push/pull dynamometers are typically held by the subject in both hands at chest level with the subject required to apply either a maximal pushing and/or pulling effort. Upon application of force the device displays a visual record of maximum effort. Unfortunately to date, most dynamometers have been constructed for adult use and, consequently, are not suitable for use by children due to inappropriate equipment size and force thresholds being too high (Jette et al., 1989). In the ACHPER Survey (Pyke, 1985), in which an adult push-pull shoulder dynamometer was used, boys aged 9 years recorded a mean pushing score of $9.3 \pm 3.4$ kg and a mean pull strength of $9.9 \pm 3.2$ kg. Mean results for 9-year-old girls were $10.1 \pm 4.1$ kg (push) and $8.8 \pm$
2.8 kg (pull). No discussion of the upper limb static strength results or correlation between collected variables were made in the ACHPER survey.

Basketball Throw: The basketball throw (BT) is an assessment task that was developed by the Australian Sports Commission (1993) to specifically evaluate upper limb power in children. This task is performed with the subject in a stationary seated position, ensuring only upper limb movement can be used (see Section 3.3.4). The subject is required to perform a basic chest pass, using a size 7 basketball, for maximum distance. The maximum horizontal displacement of the ball is then recorded as an indication of upper limb power, whereby greater upper limb power will result in the ball travelling a greater horizontal distance. The basketball throw task is cost effective, requires minimal subject familiarisation, and is quick and easy to administer in the field. Results of the basketball throw test obtained by the NSW Schools Fitness and Physical Activity Survey (Booth et al., 1997) of children aged 9 and 10 years (n = 1118), indicated boys and girls scored a mean basketball throw distance of 3.3 m and 3.0 m, respectively. Whereas this study investigated the relationships among rurality, socioeconomic status, cultural background and explosive strength, no analysis was made of the relationship between body composition and upper limb explosive strength. Furthermore, no studies were found which assessed the relationship between upper limb power and obesity in prepubescent children.

Although several studies have investigated the relationship between body composition and upper limb strength in children (Lamphiear, et al., 1976; Gilliam, et al., 1979; Sunnegardh, et al., 1988; Cotton, 1990; Woods et al., 1992), few have specifically targeted obese children or non-weight-bearing testing procedures. Blimkie and associates (1989) studied the effects of obesity on isometric and isokinetic strength of 9 to 13 year old boys. The authors concluded that the two groups of children, 13 obese and 11 non-obese subjects, exhibited similar muscle tissue composition and strength characteristics. When absolute strength was assessed, the obese boys recorded higher scores than the non-obese boys, although when scores were normalised for body weight the obese boys had reduced strength.
compared to the non-obese boys. The authors suggested that obese children may subsequently register poorer performances on activities that would require movement of their body against gravity, that is, performance on daily functional tasks. A study by Malina et al. (1995) compared absolute and relative strength of obese and non-obese girls. Larger subjects, aged between 7 and 17 years, generally displayed higher absolute strength scores but when strength and power output were expressed relative to body weight the leanest girls appeared stronger. These results suggest that heavier children, as a consequence of their increased body mass, are at a functional disadvantage when required to perform daily tasks compared to their lean counterparts. However, no studies were located to directly examine this issue.

2.3.3 Lower Limb Alignment

The acquisition of independent standing and ambulation in early childhood is initially characterised by inefficient, exaggerated postures that provide initial stability to the child. As the child's physical structure matures, biomechanical and physiological changes occur within the muscles and joints enabling the musculoskeletal system to generate sufficient strength and co-ordination to move against the external forces and to maintain biomechanical alignment (Donatelli, 1990). Gait studies conducted on children have found that by 6 years of age an adult pattern of movement is evident (Norlin et al., 1981; Berger et al., 1984; Sutherland, 1984) with only minor changes in fundamental parameters occurring thereafter. This suggests that both standing and walking characteristics of children aged over 6 years can be compared to those of adults.

Static and dynamic evaluations of lower limb alignment are clinical tests used to identify potential abnormalities of the musculoskeletal framework of the body. For example, alignment of the foot relative to the leg, thigh, and upper body is often examined to characterise lower limb musculoskeletal integrity. In normal standing, the ankle (subtalar joint) should be in a neutral position and the line of weight-
bearing* should pass through the pelvis (at the superior iliac spine), the patella, and the second metatarsal as viewed from the sagittal plane (see Figure 2.3). The tibia and the forefoot should be perpendicular in the frontal plane. The tibia should also be in line with the heel in the frontal plane, which is best observed from the posterior aspect (Root et al., 1977; Cailliet, 1980; Bordelon, 1990).

Two static evaluative procedures, standing tibial measurement and standing calcaneal measurement**, are often used to assess the position of the subtalar joint relative to the tibia as a result of weight-bearing (Wooden, 1990). With the limb in

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* The line of weight-bearing is bilateral in nature and passes through each lower limb. This concept should not be confused with the line of gravity which, in normal standing, is a single line passing through the midsagittal plane of the body (Kreighbaum & Barthels, 1996).

** Further details of the method by which both standing tibial measurement and standing calcaneal measurement are calculated are explained in detail in Section 3.3.4.
Literature Review

a non-weight-bearing position, lines are drawn on the posterior aspect of the lower third of the leg to identify the position of the tibia and calcaneus. The two lines are separate but line up continuously in space and, upon weight-bearing, can indicate deviation into inversion and eversion from the vertical (Wooden, 1990). A study by Root et al. (1977) found that upon weight-bearing excessive tibial varus and subsequent pronation of the subtalar joint resulted in the medial aspect of the foot contacting the supporting surface. The cause for this deviation, however, was not identified. Furthermore, Wooden (1990) noted that no normative data existed with respect to standing tibial or calcaneal position. Any effect obesity may have on the standing tibial or calcaneal measurement was also not located in the literature.

2.3.4 Foot Structure

The foot is the terminal link in the lower kinetic chain that opposes the effect of weight-bearing forces on the human body during ADL. Normal foot mechanics are maintained by the musculoskeletal tissue of the lower limbs functioning within a prescribed ROM. Musculoskeletal tissue dysfunction may result in abnormal foot mechanics which may in turn lead to pain, injury, or deformity of the leg and/or foot. Excessive weight-bearing, in obese adults results in altered foot mechanics, indicated via abnormal foot/ground contact patterns (Cailliet, 1980; Messier & Davies, 1989; Messier et al., 1994). Messier et al. (1994) also postulated an association between poor foot mechanics in adults and the limited involvement by obese individuals in ADL or exercise regimes. Implications of this postulation include a perpetuation of obesity via limited physical activity induced by foot dysfunction and a poor prognosis for obese children. A structurally and functionally efficient foot is imperative for non-pathological stance and gait with any deviation from the normal growth and development of the foot likely to cause problems in daily functioning. Therefore, any assessment of functional capacity must also include evaluation of foot structure.

Whereas the shape, structure and function of both the normal and pathological foot have been widely researched (Hicks, 1953; Kleiger & Mankin, 1961; Cailliet, 1980; Wilkinson et al., 1995), there is a paucity of research which has investigated the
effect of excess body mass on the foot, especially the prepubescent foot. In the normal infant’s static foot a certain degree of ligament laxity, or pronation, is present. As weight is gained with age the tensile strength of the ligamentous and muscular structures of the foot increases so that by approximately 6 years of age the child’s foot takes on the characteristics of an adult foot. If laxity continues with excessive weight gain, however, a position of extreme pronation, also known as a lowered longitudinal arch or flat foot, may develop, leading to problematic adolescent or adult feet (Cailliet, 1980; Wenger et al., 1989; Donatelli, 1990). Rose et al. (1985), Staheli et al. (1987), Gould et al. (1989) and Forriol & Pascual (1990) have all investigated the structure of the longitudinal arch in the child’s foot. It was generally concluded from these studies that morphological flat feet were characteristic of infant feet with development of the arch continuing throughout childhood to reach completion by the age of approximately 6 years.

Various methods for assessing foot surface area and longitudinal arch characteristics have been developed, including the Harris and Beath technique (Welton, 1992), radiographs, pedotopographs, and the pedograph. The Harris and Beath footprinting technique, although inexpensive and noninvasive requires sufficient space for a large walkway to be assembled and necessitates the use of specific paper and the application of talcum powder to the feet (Rose et al., 1985). Pedotopographs and radiographs both require expensive and complex equipment (Gould et al., 1989; Wenger et al., 1989) thereby limiting their use as a field assessment technique, and radiographs are also an inappropriate research tool for healthy children due to radiation exposure (Cavanagh & Rodgers, 1987). The pedograph, however, by providing a distinct outline of the foot using an inked membrane and paper (see Section 3.3.6), is a simple, noninvasive, reliable method to permanently record foot surface area and longitudinal arch characteristics (Wu, 1990). Furthermore, the pedograph is a small unit suitable for transportation, is inexpensive and very easy to administer, thus making it more practical for testing large numbers of young subjects in the field compared to other available methods.
Unfortunately to date, studies examining the longitudinal arch of the foot, as determined by footprints, of prepubescent children have been limited in terms of subject number and assessment of body composition. The only investigation not restricted to less than 30 subjects in a single age group was that of Forriol & Pascual (1990). In this study a maximum of 298 subjects’ footprints, in each of five age categories; 3 to 4, 5 to 8, 9 to 11, 12 to 14, and 15 to 17 years, were examined for Footprint Angle (FA) and Chippaux-Smirak Index (CSI)* and therefore, provided a representative sample of the population (see Table 2.2). An increase in FA and a decrease in CSI were evident in children under 9 years of age, after which time little change was noted. Therefore, the lowered arch, typical of the infant’s foot, was no longer present at or about 9 years. The mean FA and CSI of girls and boys in Groups II (5 to 8 years) and III (9 to 11 years) of the study of Forriol & Pascual (1990) are presented in Table 2.2. However, no consideration was given to the possible influence of body size on foot shape in this study.

Table 2.2
Mean Footprint Angle (FA) and Chippaux-Smirak Index (CSI) in both feet of prepubescent children (adapted from Forriol & Pascual, 1990).

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Girls (n = 591)</th>
<th>Boys (n = 322)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>II (5 to 8 years)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FA</td>
<td>40.76°</td>
<td>40.89°</td>
</tr>
<tr>
<td>CSI</td>
<td>32.42%</td>
<td>29.18%</td>
</tr>
<tr>
<td>III (9 to 11 years)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FA</td>
<td>47.58°</td>
<td>47.05°</td>
</tr>
<tr>
<td>CSI</td>
<td>27.66%</td>
<td>25.16%</td>
</tr>
</tbody>
</table>

Only two studies were located that examined an association between foot structure and body mass. Welton (1992) analysed the standing footprints of 116 children between 1 and 12 years of age. The author reported that the shape of the foot was influenced by body type, with broader footprints being associated with a plump, obese or stocky build. Similar findings were reported in a study by Hennig et al. (1994) that identified body weight as a major influence on the magnitude of the

* The methods by which both FA and CSI are calculated are explained in detail in Section 3.4.4.
pressures under the feet of 125 children aged 6 to 10 years. Neither study elaborated on any effect excess weight may have on foot development or efficiency. Welton (1992), however, suggested that, although many footprints registered outside the normal range, they would not necessarily require intervention or treatment but rather require monitoring for development of potential foot problems. In a study of the longitudinal arch of 441 subjects aged between 1 and 80 years, Staheli et al. (1987) concluded that within the normal range, flexible flat feet did not require medical intervention and that treatment of flexible flat feet 'beyond the normal range remained controversial' (p. 428). Of approximately 255 children tested, some of those within the 3, 4, 5, 6, 8, 9, 11, and 13 year old age groups recorded values outside the normal range, but the exact number was not included in the results presented by Staheli et al. (1987). Wenger et al. (1989) also suggested that treatment of flexible flat feet in children was not warranted and that, if the condition continued into adulthood, it should be treated at this time. Consequently, the relationship between excessive body mass in prepubescent children and foot structure remains uncertain.

2.4 Summary

Whereas comprehensive research has been conducted into the detrimental effects of obesity on general health and well-being there is limited information concerning possible effects of obesity on the musculoskeletal system, in particular the weight-bearing component of this system, the lower limbs. As the prevalence and cost of obesity in industrialised western society continues to escalate, and with the belief that obese children typically become obese adults, it is imperative that an investigation into the effects of obesity on functional capacity and possible complications experienced by these children be conducted. It was therefore, the aim of the present study to assess the performance of functional tasks by prepubescent children, particularly tasks demanding musculoskeletal functional capacity, to determine whether obesity affected a child's ability to successfully perform these tasks.
Chapter 3

Methods

3.1 Subjects

Two hundred and twelve male and 219 female Grade 3 students (mean age = 8.5 ± 0.5 years) who provided individual and written parent/guardian consent, participated as subjects for this study. Although two subjects with a musculoskeletal disorder unrelated to obesity were tested with their classmates, their data were excluded from analysis. It was considered that musculoskeletal disorders unrelated to obesity would impede natural movement and therefore confound the functional capacity results. Prepubescent children were selected as subjects with the belief that obesity is evident by 6 or 7 years of age and due to the dramatic increase in the number of obese prepubescent children (see Section 2.1). Although children aged 6 to 7 years were initially pilot tested for this study, it was apparent that these children were unable to comprehend easily task requirements and therefore children aged 8 to 9 years were selected.

To recruit subjects, an Information Package (see Appendix B) explaining the purpose of the study and the testing procedures was distributed to the principals of 20 primary schools that were randomly selected from the 52 primary schools in the Wollongong Education District. Twenty schools were initially contacted with the intention of targeting at least 30% of Wollongong primary schools to ensure sufficient statistical power (Department of Applied Statistics, University of Wollongong, personal communications, 1996).

Eighteen of the 20 principals gave consent for their schools to participate in the study. A visit to each of these 18 schools was conducted to locate a suitable testing venue and to schedule a date for testing. An Information Package and Informed Consent Form (see Appendix C) were then sent to the parents/guardians of all
Methods

Grade 3 students at each school. Classroom teachers were also issued an Information Package. Based on this procedure the 431 consenting subjects were identified and recruited to participate in the study.

Before commencing the study, ethics approval was obtained from the University of Wollongong Human Research Ethics Committee and the NSW Department of School Education, with all testing conducted according to the Statement of Human Experimentation (National Health and Medical Research Council, 1994b).

3.2 Experimental Protocol

A group of 16 postgraduate and undergraduate students from the University of Wollongong were trained in the necessary testing protocols before commencing the study and served as the test-team. To ensure reliability, each test-team member was responsible for, and restricted to, recording functional capacity data for the protocols that they had been trained for and with the same test equipment being used throughout the entire study. All test equipment was transported to each primary school on the day of testing and assembled prior to, and then disassembled upon completion of, the testing session. A testing session lasted between 2 to 4 hours during which time between 13 to 54 Grade 3 students were assessed. Testing was co-ordinated to complete all assessments in 18 testing sessions, which were scheduled during school hours (9:00 am-3:00 pm), within 5 weeks.

During a testing session the following physical characteristics and functional capacities of each subject were assessed:

1) height and mass,
2) flexibility during forward trunk flexion,
3) lower and upper limb strength and power,
4) lower limb alignment, and
5) foot structure.
Methods

All subject instructions were designed considering the cognitive development of prepubescent children to ensure optimal performance of each task. This required creative modifications to the standard procedures used for testing adults due to the unique cognitive demands of testing prepubescent children (for example, the use of ‘smiley faces’ and ‘stars’ to reach for in Section 3.3.2 and 3.3.3).

All tasks, except the jumping tasks used to assess lower limb strength and power, were performed with the children in bare feet. Bare feet ensured any inconsistencies caused by variations in footwear were removed and facilitated ease in measurement. However, to minimise possible negative effects of the ground reaction forces generated at landing during the jumping tasks, subjects were instructed to wear their sports shoes and socks.

To initiate each testing session, the classroom teacher introduced the chief investigator to all students in a consenting class. The chief investigator then briefly re-explained the procedure for the study to the children. Those children, with parental consent, wishing to participate as subjects were escorted in pairs, or groups of three, to the testing venue which consisted of 10 testing stations. At Station 1 a white adhesive sticker was placed on each child’s right hand on which the school and subject code were clearly identified. The subjects then proceeded individually (to ensure privacy during assessment) through the circuit of tasks (see Figure 3.1). As they reached a new station they were provided with a simple explanation and/or demonstration of the required task prior to being assessed. Before the flexibility, strength and power tasks the subjects followed a prescribed warm up (see Appendix D) and were allowed at least one submaximal practice attempt to minimise injury potential. Two assessable attempts at each task were then required. The circuit took approximately 20 minutes for each subject to complete. Upon completion, the subject code sticker was removed, subjects were thanked for their involvement and a participation sticker was issued, before being escorted back to the classroom.
Methods

3.3 Data Collection

3.3.1 Anthropometric Assessment

Height was measured to the nearest millimetre (mm) using a Mentone standard portable stadiometer while the subject stood in the anatomical position. A spirit level was attached to the stadiometer arm for greater accuracy and the stadiometer was calibrated before each testing session using a meter ruler. Body mass was measured to the nearest 0.05 kilogram (kg) using UC-300 Precision Medical Scales.
Methods

with subjects wearing minimal clothing consisting of either a T-shirt and shorts or a T-shirt and skirt. The scales were also calibrated before each testing session. Two height and two body mass recordings were taken with the mean scores used to later calculate BMI (see Section 3.4.1).

3.3.2 Flexibility
Flexibility displayed in forward trunk flexion and an ability to touch the toes were evaluated using the S&R test (see Section 2.3.1; Pyke, 1985). Subjects were seated on the floor, legs extended at the knees, with the soles of both feet flat against the front of a S&R box, which was stabilised against a wall. With one hand placed over the other, palms down, hand and fingertips level, the subject was instructed to slide the recording indicator of the S&R box slowly and smoothly with their fingertips as far along the box as possible. A research assistant placed her hands over the subject's knees to ensure the subject's legs remained extended (see Figure 3.2). The subject was instructed to hold the maximum reach position for approximately 3 s. A score of 0 indicated the subject was able to reach to the level of their toes. A negative score, in centimetres, indicated the distance by which the toes were not reached, whereas at positive score indicated the distance by which the subject exceeded the level of their toes. Two recordings were taken and the further

Figure 3.2  Sit and reach starting position.
distance was used as a representative measure of forward trunk flexion. The ability to flex the trunk forward and reach to the toes facilitates successful performance in activities such as foot hygiene, doing up laces or buckles on footwear and retrieving objects from floor level and was therefore deemed a relevant measure of functionality in the present study.

3.3.3 Lower Limb Strength and Power

**Vertical Jump:** The VJ test was used in the present study to provide a reliable measure of lower limb power in which subjects must move their body mass against gravity (see Section 2.3.2). The fingertips of the subject's right hand were covered with a fine chalk dust. Subjects then stood beside a 110 x 150 cm piece of black felt which was securely fixed to a vertical reference at a maximum height of 230 cm above ground level. Subjects were asked to stand motionless and focus their eyes on a marker (a smiley face), placed at approximately eye level in front of the subject.

With the left arm by the left side of the body, each subject was instructed to reach upwards with their right arm, elbow fully extended and make a chalk mark on the felt with the tips of the right fingers (see Figure 3.3). The subject then jumped for maximum height again, placing a mark on the felt with the fingertips. To ensure maximal effort the subjects were encouraged to 'jump for the stars' which were placed on the superior edge of the black felt (see Figure 3.3). This vertical jump procedure was modified from that of Arnot & Gaines (1986) where subjects faced the vertical reference to jump. Based on pilot testing, it was believed injury could occur during jumping if subjects jumped facing the wall, thereby necessitating the stance modification. The difference between the standing reach height and the maximum jumping height was measured to the nearest 0.5 cm. Two recordings were taken with the greater height used as an indication of lower limb power during vertical jumping.
Methods

Figure 3.3  Subject reaching upward to mark standing height for the vertical jump test.

Standing Long Jump: The SLJ was also used in the present study as a field measure of lower limb power (see Section 2.3.2). Subjects commenced with the front of their shoes behind a start line, feet approximately 10 cm apart, parallel to each other and perpendicular to the start line (Pyke, 1985). The subjects' arms were flexed at the elbows and positioned against the front and back of the body to restrict arm assistance in gaining further horizontal distance (see Figure 3.4). By restricting arm motion, the task better assessed lower limb power as compared to jumping technique (see Section 2.3.2). Subjects were encouraged to jump as far as possible by 'trying to land on the smiley face' placed on the floor in front of them. The distance jumped from the start line to the nearest back-of-shoe placement was
measured in centimetres. Two trials were recorded and the furthest distance used as a representative measure of lower limb power during horizontal jumping.

**Figure 3.4** Starting position for the standing long jump test.

**Sit-to-Stand Transfer:** Adequate lower limb strength is required to successfully rise from a chair, particularly when arm use is not permitted and the chair height is low (see Section 2.3.2). To assess functional leg strength, subjects were required to rise from a 33 cm high box (≈ 25 % of standing height) while their feet remained stationary on a height adjustable platform. The subject’s legs were positioned at 90° to the platform, feet approximately 10 cm apart and parallel to each other. The height of their feet was then adjusted to achieve a consistent knee angle of 65-70°,
orientating the subject's thighs below the horizontal to increase the degree of lower limb strength required to complete the task (see Figure 3.5).

![Diagram of knee angle](image)

**Figure 3.5** Knee angle in the starting position for the STS transfer.

To standardise the rising movement, subjects were seated in an upright position with their arms flexed at the elbows and positioned against the front and back of the body. While focussing on a 'smiley face', located 1 m in front at standing eye level, subjects were asked to rise as naturally as possible without using their arms (see Figure 3.6). Two rising trials were performed, with two additional trials allowed if subjects experienced difficulty rising. If, in rising, they were still unable to reach a standing position after the four trials, the researcher then assisted the subjects.

A Panasonic M7 VHS Movie camera (25 Hz) was used to film each rising sequence, in the sagittal plane (Wretenberg *et al.*, 1993). Two-dimensional analyses of the STS task have been frequently used as an accurate method to study the kinematics of the rising motion (Ellis *et al.*, 1984; Arborelius *et al.*, 1992; Roebroeck *et al.*, 1994). The camera was mounted on a tripod positioned approximately 4 m from the subject, 95 cm above the ground and levelled with a spirit level. A metre ruler, also levelled, was filmed before and upon completing each testing session and whenever camera position was adjusted. The 0 cm and
100 cm points on the ruler were clearly identified to act as a horizontal reference and to enable later conversion of the video image into actual distances. The camera was started before task explanation and continued running throughout the entire assessment procedure, thereby capturing each STS transfer attempt. Markers
Methods

placed in the field of camera view identified the school, subject code and trial number.

Selected anatomical landmarks were identified on the subject’s body with black adhesive markers (20 mm diameter) contrasted against a white adhesive tape background (see Figure 3.6). Marker locations were selected to enable later computation of leg, thigh and trunk segment motion and included:

1) the lateral malleolus of the fibula,
2) the lateral femoral epicondyle of the femur,
3) the greater trochanter of the femur,
4) the greater tubercle of the humerus, and
5) the external acoustic meatus.

To best identify movements of the skeleton, markers were placed at locations of minimal soft tissue and directly onto the subject’s skin. Possible marker displacement during the rising action, due to movement of the skin relative to the underlying skeletal structures and twisting of the segments were recognised as a limitation of the present study (Laviolette & Pierrynowski, 1988; Lamoreux, 1991). However, it was considered that the action of rising from a chair was a relatively slow task, producing limited segmental twisting and therefore should only incur minimal marker movement.

3.3.4 Upper Limb Strength and Power

Upper Limb Static Strength Test: Field tests for assessing upper limb static strength have traditionally incorporated the use of hand held dynamometers for adult use. Due to the inappropriate dimensions of adult dynamometers for use with prepubescent children (see Section 2.3.2) a custom-designed load cell tensiometer was used in the present study to measure upper limb static strength (ULSS) for both pushing and pulling movements. Technical specifications of this device are
presented in Appendix E. Before testing each subject the devise was zeroed. It was then handed to the subject who was seated on the floor with their head, shoulders, back and buttocks against a wall with their legs extended at the knees. The tensiometer was held by the subject in both hands at chest level, arms abducted, with forearms parallel to the floor (see Figure 3.7). Two maximal compression (pushing) and two maximal extension (pulling) efforts were then recorded. To obtain maximal efforts, the subjects were verbally encouraged throughout each trial (Pyke, 1985). The larger force for each procedure, measured in kilograms, was used as representative of ULSS (see Section 2.3.2).

**Basketball Throw:** The BT test was designed as an accurate field test to measure upper limb explosive strength, or power in children (see Section 2.3.2). For this test, subjects assumed the same body position as for the upper limb static strength test. A size 7 basketball (23 cm diameter) was then held against the chest with both hands (Australian Sport Commission, 1993). Maintaining this position (see Figure 3.8), subjects performed a two-handed chest pass for maximum horizontal distance with the distance achieved measured to the nearest 0.05 m. Two trials were recorded and the further distance was used as an indication of upper limb power.
3.3.5 Lower Limb Alignment

Alignment of the lower limbs relative to the ankle and foot generally changes upon weight-bearing as these structures must accommodate to bear the weight of the body. However, it is not known whether excessive body mass negatively effects this alignment (see Section 2.3.3). Therefore, lower limb alignment was recorded for each subject from a posterior aspect using a Praktica MTL B 5 35 mm camera loaded with Kodak Elite Chrome 100 slide film. Before capturing an image, four black adhesive markers (11 mm diameter) were placed on the distal third of each subject’s lower limbs while their foot was held in a relaxed non-weight-bearing position. The markers identified the midline of the lower leg and calcaneus (see Figure 3.9). After being marked, the subject stood in the anatomical position on a raised level platform (Reebok Step Trainer) with their feet parallel. In this position they were instructed to remain motionless and focus their eyes on a ‘smiley face’, placed at approximately eye level, 2 m in front of them.

The levelled camera was mounted on a tripod, 65 cm above ground level and 150 cm from the near edge of the raised platform. An exposure meter directed toward the subject’s lower limbs determined the light intensity and therefore the f-stop and
shutter speed settings required for optimum clarity of the subject image. A cable shutter release, attached to the camera was used to operate the shutter to avoid camera movement when the slides were taken. Both the school and subject code were identified by labels placed in the camera’s field of view. Two images per subjects were captured and, after processing, the clearest image was selected for analysis (see Section 3.4.3 for detail).

![Image of the lower leg and calcaneus](image)

Figure 3.9 Identification of the lower leg and calcaneus.

### 3.3.6 Footprint Assessment

Whether excessive weight-bearing due to obesity is detrimental to foot structure during the childhood is not known (see Section 2.3.4). Therefore, to determine the effect of obesity on foot structure, left and right footprints for each subject were recorded using a Productos Suavepie pedograph. The pedograph was positioned on a level surface and the under side of the membrane was inked before commencing each testing session and after approximately every five subjects, or as required. A piece of pedograph paper, on which the school and subject code were clearly identified, was placed beneath the membrane and the membrane lowered into position. The foot to be imprinted was positioned parallel to and above the membrane. The subject was assisted in lowering the foot onto the membrane before being instructed to stand motionless with their weight distributed evenly over both feet. Once in position for approximately 2 s, the foot was removed carefully and swiftly off the pedograph. Two outlines of each foot were taken and stored for later analysis (See Appendix F).
3.3.7 Reliability of Functional Capacity Assessment

Prior to data collection, proficiency and consistency of the testing protocols were established by a series of pilot tests. Each research assistant (or pair of assistants) was required to assess three children performing the task that they were responsible for on three separate occasions. Reliability intraclass correlation coefficients (ICC; Vincent, 1995) ranging from $R = 0.850$ to $R = 1.0$ were calculated for these preliminary tests, indicating that the test results were highly reproducible.

3.4 Data Analysis

Raw data obtained from each assessment procedure were entered into Microsoft Excel version 5.0 spreadsheets and analysed by the chief investigator. The analysis procedures are documented in this section. Data that did not require further analysis (S&R, VJ, SLJ, ULSS and BT tests) were statistically analysed (see Section 3.5).

3.4.1 Analysis of the Anthropometric Data

Means for both the height (m) and body mass (kg) recordings were calculated for each subject. Individual BMI scores were then calculated using the standard Quetelet Index protocol (see Equation 2.1). The BMI scores (rounded to the nearest 0.1) were used to classify subjects according to percentiles and gender (Wilcken et al., 1996).

### Table 3.1 Classifications used to describe the subject sample (Wilcken et al., 1996).

<table>
<thead>
<tr>
<th>Group</th>
<th>Percentile Range</th>
<th>Weight Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>&gt; 95th</td>
<td>Obese</td>
</tr>
<tr>
<td>II</td>
<td>90th – 95th</td>
<td>Overweight</td>
</tr>
<tr>
<td>III</td>
<td>10th – 90th</td>
<td>Normal</td>
</tr>
<tr>
<td>IV</td>
<td>5th – 10th</td>
<td>Borderline Underweight</td>
</tr>
<tr>
<td>V</td>
<td>&lt; 5th</td>
<td>Underweight</td>
</tr>
</tbody>
</table>
3.4.2 Analysis of STS Transfer

Digitising the STS Transfer: Video images of the STS transfer performed by a representative sample of subjects in each of the upper, middle and lower BMI percentile ranges (>95th, 50th and <5th respectively) were selected for further analysis. Thirteen subjects were selected from the upper range (mean BMI = 26.89) and matched for age and gender with subjects from the middle (mean BMI = 17.76) and lower (mean BMI = 14.05) ranges. Trials where selected if all anatomical landmarks were clearly visible and the entire rising procedure was captured.

The videoed data for the subjects were relayed from a Panasonic NV-D48 videocassette recorder to a MTC Pentium II personal computer via a video grabber card using the Matrox Rainbow Runner Studio software package. This package converted the analogue video signal to a digital representation of the picture. The image was then displayed on a CTX, 43 cm colour monitor for digitising using the Hu-m-an™ software package. A trial consisted of five frames before the STS transfer commenced to five frames after the subject had reached an upright position. Five frames were selected because subjects started and finished the STS transfer in a stationary position. One trial for each subject was digitised.

The coordinate data (x and y values) of each body landmark (lateral malleolus, lateral epicondyle of the femur, greater trochanter, greater tubercle of the humerus, the external acoustic meatus and a fixed reference point) were manually digitised following the same sequence for each frame (25 Hz). The fixed reference point, an immovable marker located on the adjustable platform within the field of view of the camera, was included to assess camera stability and film alignment. A horizontal reference (one metre ruler) was digitised before each trial to enable representation of the digitised data from pixels to real values (multipliers ranged from 0.00211 to 0.00255 m). The digitised data were then smoothed using a second order two pass Butterworth filter and a cut-off frequency of 6 Hz (Winter, 1990).
Methods

Analysis of the Digitised Data: The rising motion was divided into separate phases (adapted from Coghlin & McFadyen, 1994) which included:

1) Preparation Phase: from first notable trunk movement until maximal trunk extension was reached.

2) Transition Phase: from maximal trunk extension (or from first notable trunk flexion if no preparation phase was required) until just prior to seat off.

3) Extension Phase: from seat off until last notable movement of the external acoustic meatus when in erect stance.

For each phase of motion the following kinematic parameters were obtained using the Hu-m-an™ software and the video images for each of the 39 subjects selected in the representative sample:

1) Preparation Phase:
   a) time (s) taken from initiation of trunk movement to maximum trunk extension, and
   b) maximum value for trunk angular displacement (°), defined as the angle between the line from the greater tubercle of the humerus to the greater trochanter of the femur and the vertical line through the hip joint (VLH; see Figure 3.10).

2) Transition Phase:
   a) time (s) from maximum trunk extension, or from initiation of trunk flexion, to just prior to seat off,
   b) maximum value for trunk angular displacement (°) relative to the VLH (see Figure 3.11), and
   c) peak trunk angular velocity (°.s⁻¹).
Methods

3) Extension Phase:
   a) time (s) from seat off until last notable movement of the external acoustic meatus (subject attaining an upright stationary position),
   b) total amplitude of trunk motion throughout the STS transfer (°), and
   c) total time (s) to rise throughout the STS transfer.

![Diagram of trunk angular displacement relative to the vertical line through the hip (VLH)](image)

**Figure 3.10** Preparation phase trunk angular displacement relative to the vertical line through the hip joint.

![Diagram of trunk angular displacement relative to the vertical line through the hip (VLH)](image)

**Figure 3.11** Transition phase trunk angular displacement relative to the vertical line through the hip joint.

**Reliability of the Digitising Procedure:** To ensure reliability in the digitised data, the chief investigator completed the entire digitising procedure. Five sets of data (consisting of 30 frames each) were digitised on three separate occasions to assess reproducibility of the procedure. An ICC of $R = 1.0$ was calculated which indicated a high correlation between data sets (Vincent, 1995).
Methods

To assess the accuracy of the digitising system a series of defined points were located on the digitising screen. This process was repeated numerous times with co-ordinate reproduction within ± 1 pixel. Therefore the digitising unit was shown to produce reliable data.

3.4.3 Analysis of the Lower Limb Alignment Data

The slides of each subject’s lower limbs were projected onto a white board using a Kodak Carousel S-AV 1010 Projector. Standing tibial measurement (STM), in degrees (°), was calculated as a deviation from the vertical weight-bearing line into tibia varus or valgus. A goniometer (30 cm length) was used to indicate the angle between the line bisecting the two markers placed on the distal third of the tibia and the horizontal (see Figure 3.12). This angle was subtracted from 90° to indicate deviation from the vertical.

![Figure 3.12](image-url) Recording the standing tibial measurement (Wooden, 1990, p 140).

Standing calcaneal measurement (SCM) was then measured, as the angle (°) between the line bisecting the two markers placed on the calcaneus and the horizontal (see Figure 3.13). Again the resultant angle was subtracted from 90° to give a vertical deviation. Angles were taken from both the right and left lower limbs.
Methods

3.4.4 Analysis of the Footprint Data

All footprints were examined for print quality and the clearest left and right prints for each subject were selected for analysis. The FA and CSI were then obtained from each of the footprints following the procedures of Forriol & Pascual (1990). To obtain FA a straight line was drawn (A-A’) connecting the most medial points at the heel and at the forefoot. A second line (A-d) was then drawn from point A to the apex of the concavity of the medial arch (point d). The resultant angle at point A (α) constituted the FA (see Figure 3.14.). Footprint angles were then categorised into flat arch (0° - 29.9°), lowered arch (30° - 34.9°), intermediary arch (35° - 41.9°) and normal arch foot types (42°+; Forriol & Pascual, 1990). To calculate CSI a line was extended from point A to the widest section of the forefoot (line b). A parallel line was then constructed (line c) to identify the narrowest area of the medial arch (see Figure 3.14.). The length of line c was then divided by the length of line b and the result expressed as a percentage. The minimum value, 0%, indicated a high arch, 0.1% to 29.9% indicated a normal foot index, 30% to 39.9% indicated an intermediary arch, 40% to 44.9% indicated a lowered arch and a large percentage, 45% or above, indicated a morphological flat arch foot. To ensure reliability in the FA and CSI results the chief investigator completed all analyses of the footprint data.
Methods

Figure 3.14  Parameters used to define the Footprint Angle and Chippaux-Smirak Index (Forriol & Pascual, 1990, p 102).

3.5  Statistical Analysis

3.5.1  Functional Capacity Data

The dependant variables analysed in the present study included:

1)  BMI score,
2)  the maximum effort recorded for the S&R, VJ, SLJ, ULSS (push and pull) and BT,
3)  STS transfer performance represented by the duration of each phase of the transfer (see Section 3.4.2), angular trunk displacement and angular trunk velocity,
4)  lower limb alignment characterised by SCM and STM, and
5)  foot structure characterised by FA and CSI.
Means, ranges and standard deviations for these dependent variables for boys and girls and the total sample were calculated. Data for the boys were compared to that obtained for the girls using independent $t$-tests (normally distributed data) or Mann-Whitney rank sums tests if data were not normally distributed.

3.5.2 Relationship Between BMI and Functional Capacity Data

To establish the strength of the relationship between BMI and functional capacity, Pearson product moment correlations were calculated between each of the subject’s functional capacity test scores and their BMI score. A relationship was deemed significant at $p \leq 0.05$.

3.5.3 Effect of Obesity on Functional Capacity Data

To determine the effect of obesity (as characterised by BMI) on functional capacity, functional test results were selected from subjects with a BMI above the 95th percentile, subjects with a BMI from the 50th percentile and subjects with a BMI below the 5th percentile, using the percentile data of Hammer et al. (1991) and Harvey & Althaus (1993). The aim of this grouping was to compare the obese, normal weight and underweight (see Table 3.1) children’s performances. BMI values for the original sample, however, were skewed towards the higher values (see Figure 4.1) resulting in an insufficient number of subjects with a BMI below the 5th percentile ($n = 6$ or 1.4%). For this reason, the underweight group was discarded and only functional test data of subjects above the 95th percentile (Hammer et al., 1991; Harvey & Althaus, 1993) and at the 50th percentile were selected for comparison. This classification system resulted in the top 10% of subjects in the present study ($n = 43$) being selected and classified as Obese. An equal number of subjects, matched for age and gender, from the middle BMI range (equating to the 50th percentile as indicated by Hammer et al., 1991 and Harvey & Althaus, 1993) were classified as Non-obese*.

* For the STS transfer, data were compared for 13 Obese and 13 Non-obese subjects rather than 43 in each group (see Section 3.4.2).
Methods

The data for each dependent variable were tested for normality using Kolmogorov-Smirnov tests. For those dependent variables that were normally distributed, independent \( t \)-tests were then performed to identify any significant differences \( (p \leq 0.05) \) between the Obese and Non-obese subjects. Data not normally distributed were analysed using Mann-Whitney rank sum tests to determine significant differences \( (p \leq 0.05) \) between the subject groups’ performance on the functional tests.

All statistical procedures were conducted using Jandel SigmaStat ® version 2.03 statistical software package.
Chapter 4
Results and Discussion

4.1 Anthropometric Data

Descriptive information pertaining to the physical characteristics of the subjects who participated in this study is summarised in Table 4.1. The distribution of BMI scores calculated for the subjects is depicted in Figure 4.1.

Table 4.1 Height, mass and body mass index scores for the subjects.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Boys (n = 210)</th>
<th>Girls (n = 219)</th>
<th>Total (n = 429)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Range</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.34 (0.05)</td>
<td>1.18 - 1.50</td>
<td>1.34 (0.06)</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>31.7 (6.6)</td>
<td>20.1 - 55.4</td>
<td>32.1 (7.0)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>17.7 (2.9)</td>
<td>12.7 - 30.2</td>
<td>17.9 (2.9)</td>
</tr>
</tbody>
</table>

Mean anthropometric measurements derived for subjects in the present study were consistent with those reported previously in the literature. For example, Pyke (1985) reported a mean height for 8-year-old boys and girls of 1.301 m and 1.293 m, respectively, and for 9-year-old boys and girls of 1.360 m and 1.353 m, respectively. The mean mass reported by Pyke (1985) for the 8-year-old boys (28.2 kg) and girls (27.9 kg) and the 9-year-old boys (31.6 kg) and girls (31.6 kg) were also similar to the present results. Booth et al. (1997) found that Year 4 boys and girls (aged 9/10 years) displayed a mean height of 1.363 m and 1.361 m, respectively, a mean body weight of 32.9 kg, and a mean BMI of 17.6 kg/m². In both studies, no significant differences were found for the anthropometric data when comparing values obtained for boys and girls. Consistent with these results,
Results and Discussion

no significant differences were evident in the present study between the prepubescent boys and girls for height ($t = 0.263$, $p = 0.793$), weight ($T_{\text{Mann-Whitney}}^{*} = 44611.5$, $p = 0.675$) or BMI ($T_{\text{Mann-Whitney}} = 44215.5$, $p = 0.467$). Therefore, data pertaining to the relationship between BMI and functional performance and the effects of obesity on functional capacity, discussed later in this chapter, have not been separated on the basis of gender.

Figure 4.1  Distribution of body mass index scores for the subjects (including 5th, 50th and 95th percentiles, Hammer et al., 1991).

From Figure 4.1 it is evident that most subjects in the present study were classified as normal to overweight (BMI $\approx$ 15 to 20) with less than 10% of the subjects categorised as borderline underweight to underweight (BMI < 15; see Section 3.4.1 and Appendix A). Almost 15% of the subjects were classified as obese (BMI $> 20$). This figure is higher than the 13% reported by Hardcastle et al. (1997) from a sample of 476 Australian prepubescent children. Furthermore, it is suggested that the percentage of obese children in the present study is underestimated. That is,
each of the 18 participating schools reported that at least one, and more frequently two, obese children were not available for testing as they were either absent on the day of testing or chose not to participate in the study.

4.2 Flexibility Data

The distances reached by the subjects during the S&R test are presented in Table 4.2. The mean reach distances of boys and girls in the present study were less than values reported in previous research that utilised the same S&R procedure. For example, Pyke (1985) reported mean S&R test scores of 2.4 cm and 1.3 cm for boys aged 8 and 9 years, respectively, and 5.8 cm and 5.3 cm for girls aged 8 and 9 years, respectively. Whereas the reach distance for boys was only slightly less, the value for girls was two-fold less than the previously reported values. Possible causes of the between-study differences may have been that girls in the present study were less motivated to reach towards their toes than the girls assessed by Pyke (1985) or, alternatively, there has been a decrease in flexibility of prepubescent girls between 1985 and the present study. Nevertheless, in the present study girls reached a significantly greater mean distance ($t = -2.493, p = 0.013$) than boys. This finding was consistent with previous research in which 8- and 9-year-old girls reached further than boys of the same age by a mean distance of 1.06 inches ($\approx 2.7$ cm) and 1.44 inches ($\approx 3.7$ cm), respectively (Ross & Pate, 1987). These findings support the notion that prepubescent girls are more flexible than prepubescent boys (DiNucci, 1976; Branta et al., 1984; Gabbard & Tandy, 1988; Pongparpai et al., 1994).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Boys (n = 207)</th>
<th>Girls (n = 219)</th>
<th>Total (n = 426)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Range</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>S&amp;R test (cm)</td>
<td>1.1 (5.7)</td>
<td>-11.5 - 14.5</td>
<td>2.6* (6.4)</td>
</tr>
</tbody>
</table>

* indicates a significant difference between boys and girls.
In examining the relationship between BMI and flexibility, BMI was found to be negatively correlated with the S&R test scores ($r = -0.148$, $p < 0.01$). That is, as BMI increased the S&R distance decreased. This would suggest that subjects with a large BMI score were not as efficient in terms of reaching towards their toes as subjects with a lower BMI score (see Section 2.3.1). Although significant, the relationship was only very low ($r^2 = 0.022$) indicating that only $2\%$ of the variance in S&R performance could be explained by its relationship with BMI. Gabbard & Tandy (1988) studied the S&R performance of prepubescent males and females to conclude that body composition (skinfold data at four sites) had little association with flexibility, suggesting that other factors must have contributed to the reach distance.

When comparing the S&R mean distance recorded for the Obese and Non-obese subjects, no significant difference was noted ($t = -1.915$, $p = 0.059$), although there was a trend for the Obese subjects to reach a lesser distance (see Figure 4.2). This finding was consistent with the results of Pongparpai et al. (1994) who found no significant differences between normal weight, overweight and obese children (aged 9 years) on mean S&R scores, although the Obese group also recorded the lowest flexibility score. Conway et al. (1989), who studied adult Navy recruits, proposed that estimates of percentage body fat correlated more strongly with fitness scores (including the S&R test) than weight-height indices, although they did not indicate if any of the recruits were obese. Malina et al. (1995) also found that fatness negatively correlated to results on the S&R test in children, which was particularly evident among prepubescent girls. Further research is therefore needed to identify whether percentage body fat, as opposed to BMI, negatively impacts on the S&R performance of obese prepubescent children. Alternative measures of flexibility should also be investigated to determine any effect obesity has on the daily functional capacity of prepubescent children.
Results and Discussion

Figure 4.2  Sit and reach test scores (mean + SEM) for the Obese (n = 43) and Non-obese subjects (n = 43). A negative score indicates the subjects did not reach their toes.

4.3 Strength and Power Data

4.3.1 Lower Limb Power

Lower limb power test results are presented in Table 4.3. Mean VJ distances recorded for the boys and girls in the present study were similar to distances recorded for 90 boys and 80 girls aged 5 to 10 years (Branta et al., 1984; see Section 2.3.2). Mean SLJ distances, however, were approximately 20 cm less than figures reported by Pyke (1985) for 972 boys and 983 girls aged 8 and 9 years. As mentioned in Section 2.3.2, the distances jumped by subjects in the present study may have been limited by the restricted arm protocol whereby subjects were not permitted to use arm swing to generate momentum in order to gain greater horizontal distance. As expected, a significant difference was evident between the lower limb power of boys compared to girls on both jumping tests (see Table 4.3)
such that boys displayed more lower limb power than girls (VJ: \( t = 3.019, p = 0.003 \); SLJ: \( t = 5.723, p < 0.001 \)). A study by Hensley et al. (1982) also found that prepubescent boys displayed significantly greater lower limb power than girls when performing the vertical and standing broad jump tasks.

Table 4.3 Lower limb power data for the subjects.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Boys (n = 210)</th>
<th>Girls (n = 219)</th>
<th>Total (n = 429)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Range</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>VJ (cm)</td>
<td>24.9 (4.5)</td>
<td>14.5 – 40.0</td>
<td>23.6* (4.4)</td>
</tr>
<tr>
<td>SLJ (cm)</td>
<td>107.0 (15.2)</td>
<td>69.9 – 157.5</td>
<td>98.4* (15.3)</td>
</tr>
</tbody>
</table>

* indicates a significant difference between boys and girls.

The BMI of prepubescent boys and girls is generally believed to be similar, a finding confirmed in the present study (see Section 4.1), with significant variations in muscle mass, height and adiposity only occurring after puberty. Therefore, gender differences in lower limb power evident in the present study are more likely attributable to the effect of differences in previous jumping experience or perhaps competitive desire rather than variations in muscle mass. The level of motivation provided to both the boys and girls during testing, however, was the same in an attempt to control for this latter variable.

Both the VJ (\( r = -0.160 \)) and SLJ (\( r = -0.253 \)) were negatively and significantly correlated to BMI (\( p < 0.01 \)), indicating that as BMI increased, the vertical height and horizontal distance jumped decreased. Similar to the S&R test results, however, the relationship between lower limb power and obesity was low (\( r^2 = 0.026 \) and 0.064) such that BMI scores alone could not explain most of the variation in jumping distance.
Although low, the negative correlation evident between BMI and lower limb power was supported when comparing the Obese and Non-obese subject groups (see Figure 4.3). That is, the Non-obese subjects jumped significantly higher ($t = 2.889; p = 0.005$) and further ($t = 2.452; p = 0.016$) than their Obese counterparts. This finding was consistent with previous studies (Suzuki & Tatsumi, 1993; Malina et al., 1995; Parízková, 1996) in which obese and overweight children did not jump as far or as high as their lean counterparts. These results imply that, when required to move their larger body mass against gravity, obesity impedes the functional capacity of prepubescent children. Whether the negative effects of obesity on lower limb power translate to daily tasks, such as rising from a chair, is therefore of concern.

![Figure 4.3](image)

**Figure 4.3** Lower limb power data (means ± SEM) for the Obese (n = 43) and Non-obese (n = 43) subjects (* indicates a significant difference between the two subject groups).
4.3.2 STS Transfer

Functional lower limb strength results, as reflected in the STS transfer (see Section 3.4.2), for the Obese and Non-obese subjects are presented in Figures 4.4 and 4.6. In the present study, the total time for the Obese subjects to rise was, on average, $3.8 \pm 1.8$ s. In contrast, the Non-obese subjects rose in a significantly less average time ($1.5 \pm 0.2$ s). The only study located which examined the STS transfer performed by healthy children (Cahill et al., 1998) reported the total movement time of children between 12 months and 10 years of age. In this study, the children aged 9 to 10 years rose in a mean time of $1.4$ s. This time was consistent with studies by Wheeler et al. (1985) and Nuzik et al. (1986) which reported mean rising times for healthy non-obese adults of $1.5 \pm 0.16$ s (mean age = 24 years) and $1.8 \pm 0.3$ s (mean age = 26.4 years), respectively. These times were also similar to the times recorded for the Non-obese children in the present study.

Why the Obese subjects took longer to rise than their Non-obese counterparts becomes evident when each phase of the STS transfer process is analysed. That is, the Obese subjects spent additional time ($1.4$ s) preparing to rise, whereas no preparation time was required by the Non-obese subjects (see Figure 4.4). During this preparation, most Obese subjects (77%) moved their trunk backward (mean = $-2.7^\circ$) before initiating a forward and upward trunk motion (see Figure 4.5). Many Obese subjects repeated this procedure several times before being able to stand. Additionally, 69% of the Obese subjects required external assistance from the research assistant to successfully initiate the transition phase of the STS transfer. An increased preparation time and assistance to rise are common requirements of elderly or impaired individuals in order to successfully reach an upright position during a STS transfer due, in part, to a lack of lower limb strength (Baer & Ashburn, 1995). It is postulated that, in the present study, the Obese children may have also experienced difficulty in rising as a result of insufficient lower limb strength to move their excess body mass upright against gravity. In contrast, the Non-obese subjects required minimal backward trunk motion or assistance to rise successfully (see Figure 4.5). Once the STS transfer was initiated, the Obese subjects also spent significantly more time during both the transition phase ($t = \ldots$)
Results and Discussion

2.654, \( p = 0.014 \) and the extension phase \( (t = 2.853, p = 0.009) \) compared to the Non-obese subjects (Obese: mean = 1.05 s, SD = 0.70 s and mean = 1.26 s, SD = 0.26 s, respectively; Non-obese: mean = 0.52 s, SD = 0.13 s and mean = 1.03 s, SD = 0.13 s, respectively). Taking longer in the transition and extension phases may have provided the Obese subjects with more time to control the horizontal and vertical momentum of their excess mass to remain balanced and complete the standing procedure.

**Figure 4.4** Time spent in the three phases of the sit-to-stand transfer for the Obese \((n = 13)\) and Non-obese \((n = 13)\) subjects (* indicates a significant difference between the two subject groups) (*Preparation:* initiation of trunk movement to maximum trunk extension; *Transition:* time from maximum trunk extension or from initiation of trunk flexion to just prior to seat-off; *Extension:* time from seat-off to stationary standing position).

Comparing the initial and final mean trunk angles displayed prior to commencing the extension phase between the two groups (see Figure 4.5), the Obese subjects started their forward movement of the STS transfer with the trunk inclined backward whereas the Non-obese subjects commenced with the trunk inclined
forward. The Obese subjects also completed the transition phase in a more forward inclined trunk position, thereby moving through a significantly greater trunk ROM than the Non-obese subjects ($t = 2.346, p = 0.028$). Although the Obese subjects displayed an increased movement time and greater ROM during the transition phase, there was no difference in the mean peak angular velocity of the trunk ($t = -0.555, p = 0.584$) between the two groups (Obese = $147.7 \pm 30 \, ^\circ \cdot \text{s}^{-1}$, Non-obese = $141.3 \pm 29 \, ^\circ \cdot \text{s}^{-1}$).

![Figure 4.5](image)

**Figure 4.5** Trunk angles (from the vertical line through the hip; mean ± SD and range) at completion of each phase of the sit-to-stand transfer for the Obese ($n = 13$) and Non-obese ($n = 13$) subjects (* indicates a significant difference between the two subject groups.)
According to Ellis et al. (1984), rising from a lower chair and without arm assistance requires a high level of lower limb strength. These two factors were incorporated into the present rising task to provide a functional assessment of lower limb strength. Children were also required to assume a defined posture before rising so that lower limb strength could be assessed from a standardised position. However, restricting subjects in this manner may have influenced their coordination and confidence to stand normally (Baer & Ashburn, 1995). Furthermore, and as noted in Table 4.1, the mean height of the Obese subjects exceeded that of the Non-obese subjects by 0.06 m. Assuming that as height increases limb length increases, the Obese subjects may have been placed at a mechanical disadvantage when attempting to stand in the present study, although knee angle was held constant in an attempt to control for this effect. To determine whether mean height is a contributing factor for prepubescent children when rising, further investigation is warranted.

Subjects in the present study appeared to have both the motor control and cognitive development necessary to successfully and safely complete the STS procedure. However, as discussed previously, only 31% of the Obese subjects could complete the rising procedure without assistance. It is therefore suggested that the Obese subjects did not generate sufficient momentum to raise their increased mass by themselves. This may indicate that, similar to the jumping tasks, the Obese subjects lacked sufficient lower limb strength to move their excess mass against gravity, in this case, to reach a standing position. Insufficient lower limb strength and power, as a consequence of obesity, therefore, has the potential to reduce daily functional capacity and quality of life.

4.3.3 Upper Limb Strength and Power

Upper limb strength and power results obtained for the subject group are shown in Table 4.4. Previous studies have shown that prepubescent boys perform better on tests of upper limb strength and power than prepubescent girls (Metheny, 1941; Nelson et al., 1991; Woods et al., 1992). These tests, however, generally required subjects to move their body mass against gravity, an event seldom encountered in
activities of daily living (see Section 2.3.2). One study that assessed strength independent of body mass (Pyke, 1985), showed that, whereas 9-year-old boys recorded a superior mean pulling strength relative to girls of the same age (9.9 kg and 8.8 kg, respectively), the girls performed better than boys at the pushing task (10.1 kg and 9.3 kg, respectively). That study, however, did not identify whether the differences were significant. Results from the present study (see Table 4.4) indicated that boys were significantly stronger than girls for both the pushing and pulling tasks (push: \( t = 2.988, p = 0.003 \); pull: \( T_{\text{Mann-Whitney}} = 35386.5, p = 0.004 \)). Boys also registered greater upper limb power to project the basketball significantly further than the girls (\( T_{\text{Mann-Whitney}} = 52453.5, p < 0.001 \)). This projection distance was consistent with data from a study of Australian school children (9 and 10 years of age) where boys and girls achieved a mean throwing distance of 3.3 m and 3.0 m, respectively (Booth et al., 1997).

**Table 4.4** Upper limb strength and power data for the subjects.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Boys (n = 210)</th>
<th>Girls (n = 219)</th>
<th>Total (n = 429)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Range</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Push (kg)</td>
<td>9.2 (2.2)</td>
<td>3.5 - 16.5</td>
<td>8.5* (2.3)</td>
</tr>
<tr>
<td>Pull (kg)</td>
<td>9.3 (2.7)</td>
<td>2.8 - 17.4</td>
<td>8.6* (2.5)</td>
</tr>
<tr>
<td>BT (m)</td>
<td>3.4 (0.5)</td>
<td>1.7 - 4.7</td>
<td>3.2* (1.4)</td>
</tr>
</tbody>
</table>

* indicates a significant difference between boys and girls.

When absolute strength is assessed rather than strength relative to body weight, obese children have been shown to display equal or greater scores than their lean counterparts (Blimkie et al., 1989; Suzuki & Tatsumi, 1993). Upper limb strength and power in the present study were both positively correlated to BMI. That is, as BMI increased pushing, pulling and throwing capacity also increased. Once again, although a significant correlation was observed \( p < 0.001 \) the strength of these
correlations was low for all tasks (BT: $r = 0.219$, push: $r = 0.183$, pull: $r = 0.202$) such that factors other than BMI were accountable for the variations observed in these tasks.

Despite the low correlations, the Obese subjects displayed significantly greater upper limb power than the Non-obese subjects ($T_{Mann-Whitney} = 1588.0$, $p = 0.015$). That is, the obese children were able to propel the basketball significantly further than their lean counterparts (see Figure 4.6). However, no significant differences were evident between the upper limb strength results of the two subject groups (push: $t = 0.775$, $p = 0.441$; pull: $t = -1.418$, $p = 0.160$). Nevertheless, for all upper limb tasks in which the subjects were not required to move their mass against gravity there was a trend for the Obese children to display greater strength results (see Figure 4.7). From this finding it is suggested that Obese prepubescent children could have greater lean tissue accompanying their increased adipose tissue compared to normal weight prepubescent children. Blimkie et al. (1989), however, studied strength characteristics of obese and non-obese preadolescent boys to find no differences between the groups for muscle cross-sectional area, contractile properties or intrinsic strength. Alternatively, the Obese subjects in the present study were significantly taller than the Non-obese subjects ($t = 6.439$, $p < 0.001$). Therefore, longer limb length may have provided a mechanical advantage during the throwing task, enabling the Obese subjects to generate greater velocity to project the basketball further than Non-obese subjects, thereby achieving the greater horizontal range. Whatever the specific mechanism, it appears from the results of this study that obesity did not limit children’s functional capacity in terms of upper limb strength or power.
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Figure 4.6  Upper limb power data (means ± SEM) for the Obese (n = 43) and Non-obese (n = 43) subjects (* indicates a significant difference between the two subject groups).

Figure 4.7  Upper limb strength data (means ± SEM) for the Obese (n = 43) and Non-obese (n = 43) subjects (* the force data were recorded by the tensiometer in kilograms rather than Newtons).
4.4 Lower Limb Alignment Data

The standing calcaneal measurement and standing tibial measurement for the total subject group, for both the left and right legs, are presented in Table 4.5. No significant differences were found between the lower limb alignment of the prepubescent boys and girls. In fact, mean values for both the SCM and STM varied between the gender groups by only 0.4° and 0.2°, respectively (see Table 4.5). When ranges for both the SCM and STM were reviewed lower limb alignment measurements deviated from the vertical position by up to 13°. However, no normative lower limb alignment data were located against which to compare results from the present study.

Table 4.5  Standing calcaneal measurement and standing tibial measurement for the subjects.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Boys (n = 210)</th>
<th>Range</th>
<th>Girls (n = 219)</th>
<th>Range</th>
<th>Total (n = 429)</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCM-left (°)</td>
<td>-5.0 (4.3)</td>
<td>-13.0 – 7.0</td>
<td>-5.3 (4.0)</td>
<td>-13.0 – 8.0</td>
<td>-5.5 (4.3)</td>
<td></td>
</tr>
<tr>
<td>SCM-right (°)</td>
<td>-2.3 (4.3)</td>
<td>-12.0 – 8.0</td>
<td>-2.7 (4.3)</td>
<td>-12.0 – 10.0</td>
<td>-2.5 (4.3)</td>
<td></td>
</tr>
<tr>
<td>STM-left (°)</td>
<td>-0.3 (3.7)</td>
<td>-10.0 – 10.0</td>
<td>-0.5 (3.7)</td>
<td>-9.0 – 11.0</td>
<td>-0.4 (3.6)</td>
<td></td>
</tr>
<tr>
<td>STM-right (°)</td>
<td>0.9 (3.4)</td>
<td>-9.0 – 10.0</td>
<td>0.8 (4.0)</td>
<td>-9.0 – 11.0</td>
<td>0.8 (4.1)</td>
<td></td>
</tr>
</tbody>
</table>

* negative values indicate orientation of the proximal end of the segment away from the midline whereas positive values indicate orientation of the proximal end of the segment towards the midline.

BMI did not appear to influence SCM or STM as all correlation coefficients were below 0.05 with alpha values greater than 0.38. Furthermore, the SCM and STM measurements of the Obese subjects only varied by a maximum of 1° compared to those measurements for the Non-obese subject. Therefore, in the present study,
Results and Discussion

obesity had no significant effect on the lower limb alignment as assessed using the SCM and STM. Screening the subjects for musculoskeletal pathologies, however, may have influenced this finding (see Section 1.1) and therefore these results should be interpreted cautiously. Additionally, due to the degree of adipose tissue present on the lower limbs of the Obese compared to the Non-obese children (see Figure 3.9), the results of these measurements may have been influenced by how accurately the necessary landmarks could be located.

4.5 Footprint Data

The total subject group data for Footprint Angle and Chippaux-Smirak Index, for both the left and right feet, are presented in Table 4.6. The FA (see Section 3.4.4) results, in the present study, for both the left \( t = -3.661, p < 0.001 \) and right \( t = -4.213, p < 0.001 \) feet, were consistent with figures reported by Forriol & Pascual (1990) for children aged 9 to 11 years (see Section 2.3.4). Whereas Forriol & Pascual (1990) did not elaborate on whether gender differences were significant, significant differences were evident between FA for prepubescent boys and girls in the present study (see Table 4.6) such that, boys displayed a lower arch height than girls. Values for the CSI (see Section 3.4.4) for girls were very similar whereas values for boys were slightly less than results from the study by Forriol & Pascual (1990). Although gender differences between CSI values were not significant (left: \( t = 1.102, p = 0.271 \); right: \( t = 1.647, p = 0.100 \)), in the present study, boys again displayed a lower arch height than girls, a finding consistent with Forriol & Pascual (1990). These results suggest that variations are present in footprint parameters of prepubescent boys and girls by the age of 8 years. Studies by Didia et al. (1987) and Sandrey et al. (1996) have also identified significant differences between the footprints of boys and girls. However, Stahelli et al. (1987) measured the longitudinal arch index of males and females aged from 1 to 80 years, reporting no influence of gender. Further research is therefore warranted to determine if and when changes in foot structure between genders occur and the best method to determine the structure of the prepubescent foot (Hawes et al., 1992; Menz, 1998).
Table 4.6  Footprint Angle and Chippaux-Smirak Index for the subjects.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Boys (n = 210)</th>
<th>Girls (n = 219)</th>
<th>Total (n = 429)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Range</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>FA-left(°)</td>
<td>41.6 (14.1)</td>
<td>4.0 - 64</td>
<td>46.1* (11.6)</td>
</tr>
<tr>
<td>FA-right(°)</td>
<td>41.2 (13.7)</td>
<td>5.0 - 67</td>
<td>46.2* (10.8)</td>
</tr>
<tr>
<td>CSI-left(%)</td>
<td>26.8 (15.4)</td>
<td>0.0 - 75.7</td>
<td>25.1 (14.9)</td>
</tr>
<tr>
<td>CSI-right(%)</td>
<td>28.3 (14.5)</td>
<td>0.0 - 75.3</td>
<td>26.1 (13.7)</td>
</tr>
</tbody>
</table>

* indicates a significant difference between boys and girls

Footprint Angle for both the left and right feet was found to be negatively correlated to BMI ($r = -0.243$ and $r = -0.249$, respectively, $p < 0.001$) such that as BMI increased FA decreased. For the CSI data, a positive relationship was observed with BMI where both measures increased together. The strength of the correlation coefficients for the left and right feet ($r = 0.389$ and $r = 0.371$, respectively, $p < 0.001$), similar to the FA, were low, suggesting that most of the variance within the variables characterising foot structure could not be explained by their relationship to BMI alone.

Obese children have previously been observed to display broad footprints (Welton, 1992; see Section 2.3.4). This finding was also evident in the present study (see Figure 4.8 and 4.9) with a significant difference noted in the footprint shape between the Obese and Non-obese subjects. Obese subjects displayed a decreased FA and an increased CSI compared to their lean counterparts. A decreased angle and an increased index have been associated with a lower longitudinal internal arch, a flatter cavity and a broader midfoot area of the footprint (Cavanagh & Rodgers, 1987; Garcia et al., 1999). Lower arches have also been associated with a decrease in the integrity of the foot as a weight bearing structure.
Results and Discussion

Figure 4.8  Footprint Angle (means + SEM) for the Obese (n = 43) and Non-obese (n = 43) subjects (* indicates a significant difference between the two groups).

Figure 4.9  Chippaux-Smirak Index (means + SEM) for the Obese (n = 43) and Non-obese (n = 43) subjects (* indicates a significant difference between the two groups).
The structural changes in the foot associated with obesity may be a factor that hinders participation of obese children in physical activity. For example, if structural changes associated with obese children’s feet increase pressure within the foot or compromise foot function, this may lead to increased foot discomfort, particularly during weight-bearing activities. If so, a decline in physical activity associated with foot discomfort may perpetuate the cycle of further increase in obese children’s body mass due to inactivity, thereby increasing loads on the feet and, in turn, further exacerbating load bearing-associated foot problems. Therefore, it is suggested that obese children as young as 8 years of age are displaying structural foot characteristics which may develop into problematic symptoms in later life, particularly if their excessive weight continues. This negative impact on functional performance, during activities of daily living, could also be influenced by decreased lower limb strength and power, which were also noted in the present study.
Chapter 5
Summary, Conclusions and Recommendations

5.1 Summary of the Results

The portion of overweight and obese children in the industrialised world has increased during the past two decades to the extent that obesity is now considered a chronic pediatric disease. There are many long-term debilitating effects of obesity that may impair quality of life, including coronary artery disease, diabetes mellitus, various musculoskeletal disorders and physical restrictions in the performance of daily tasks. However, at what stage of life obesity negatively affects functional capacity is unknown. Therefore, the aim of the present study was to investigate whether obese prepubescent children were restricted, by excess body mass, during performance of basic functional activities. To achieve this aim, 431 children aged 8 and 9 years, from randomly selected schools, were assessed for physical characteristics and while performing selected functional tasks. The physical characteristics included height, body mass, lower limb alignment (SCM and STM) and footprint assessment (FA and CSI). The functional tasks included tests for flexibility (S&R test), lower limb strength and power (VJ, SLJ, STS transfer) and upper limb strength (push and pull) and power (BT).

To determine the relationship between obesity and functional capacity each subject’s scores were correlated to their BMI score. All functional capacity data, except lower limb alignment, were significantly correlated to BMI. However, as the correlations were relatively low, decrements in performance could not be predicted from obesity alone.

To identify the effect of obesity on functional capacity the performances of the top 43 subjects with a BMI score greater than the 95th percentile for their age and gender (Obese) and 43 subjects with a BMI score at the 50th percentile (Non-obese matched controls) were compared. When performances were compared, lower
Summary, Conclusions and Recommendations

limb strength and power data and footprint measurements were significantly and negatively affected by obesity. In contrast, upper limb strength and power data were not limited by obesity and no differences were apparent in the lower limb alignment data between the Obese and Non-obese children.

It was hypothesised that an increase in obesity would be associated with a decrease in flexibility during forward trunk flexion (Hypothesis 1a). In partial agreement with this hypothesis, an increase in obesity was accompanied by a decrease in forward flexion such that Obese subjects could not reach to the level of their toes whereas the Non-obese subjects could reach past their toes. The difference in reach distance, however, was not significant between the two subject groups. Therefore, Hypothesis 1a was rejected, although further research in this area is recommended (see Section 5.3).

Functional lower limb strength and power scores significantly decreased with an increase in obesity. This finding was in agreement with Hypotheses 1b and 1c which stated that an increase in obesity would be associated with a decrease in lower limb strength and power and the ability to perform a functional task such as a sit-to-stand transfer. When the Obese and Non-obese subject data were compared most of the Obese children were not able to jump as far or as high as normal weight children. The Obese children also experienced difficulty rising from a chair. These results implied that, when required to move their larger body mass against gravity, during jumping activities and during the performance of a basic daily task (such as rising from a chair), obesity impedes the functional capacity of prepubescent children. It is postulated that obese children are therefore likely to have difficulty performing other ADL in which they are require to rise from a seated position (such as getting out of bed or rising from the toilet) or moving their larger body mass up an incline (such as ascending stairs or walking up a ramp). If performing these ADL is more difficult obese children may avoid attempting them as frequently, in turn, resulting in reduced energy expenditure and
Summary, Conclusions and Recommendations

an increased likelihood of a positive energy balance. To determine the extent of this negative impact on functional performance in daily life further investigation is required.

Although Obese children were able to project the ball further than their lean counterparts, there were no significant differences in the pushing and pulling strength capacity of the two subject groups. This lead to the acceptance of Hypothesis 2, that an increase in obesity would be associated with no change in the upper limb strength and power displayed during functional tasks. Therefore, obesity did not appear to negatively influence the upper limb functional capacity of prepubescent children during the performance of daily activities, in which weight bearing was not included.

In contrast to Hypothesis 3a, that an increase in obesity would be associated with increased deviation into tibial varus, no significant differences were evident between lower limb alignment data for the Obese and Non-obese subjects. Obese subjects, however, displayed a decreased Footprint Angle and an increased Chippaux-Smirak Index compared to Non-obese subjects, confirming Hypothesis 3b. A decreased angle and an increased index have been associated with a lower longitudinal internal arch, a flatter cavity and a broader midfoot area of the footprint. Lower arches have also been associated with a decrease in the integrity of the foot as a weight bearing structure. As recommended in Section 5.3, the findings of the present study warrant further research to investigate any pathological consequences to prepubescent feet as a result of childhood obesity.

5.2 Conclusions

When required to move their extra body mass against gravity, obese prepubescent children were at a functional disadvantage compared to children of normal body mass. Of particular concern was the finding that most of the Obese children were unable to initiate rising from a chair without assistance. When not required to
move their mass against gravity, obesity did not limit the children’s flexibility or functional capacity in terms of upper limb strength or power. Although the Obese children displayed a significantly different foot shape compared to the Non-obese children the low correlation coefficients precluded the prediction of flat-feet or compromised longitudinal arch development as a result of obesity. Nevertheless, it was concluded that excess body mass may have a negative effect on the foot structure and function of prepubescent children.

Results from the present study suggest that obesity has a negative effect on children as young as 8 years of age when performing basic daily tasks compared to their lean counterparts. Therefore, appropriate interventions against this chronic disorder should commence before this age.

5.3 Recommendations for Further Research

The following recommendations for further research are based on the findings of the present study:

1) Further research should be conducted to examine the flexibility of obese prepubescent children using a variety of measures of flexibility in order to determine the extent to which obesity may influence this aspect of functional capacity.

2) Implications of the decreased lower limb strength and power displayed by obese prepubescent children warrants further investigation to identify the impact of this decrement on performing daily activities.

3) Further research is required to investigate the relationship between obesity and foot structure to determine whether obesity may prevent normal development of the prepubescent foot. It is not known if the greater prevalence of flat-footedness in the obese prepubescent child is due to the presence of a fat pad that remains or develops in the instep of the obese child,
thereby causing a form of flat-feet that may have no pathological consequences. However, it is also unknown if there is some other structural dysfunction present, as a result of excessive weight-bearing, which has caused the longitudinal arch to collapse, thereby resulting in an increased foot contact area which will have pathological consequences.
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References


References


References


References


References


References


Appendix A

Body Mass Index Charts

BMI for boys aged 2-18 years
BODY MASS INDEX


BMI for girls aged 2-18 years
Appendix B

Information Package

University of Wollongong
Department of Biomedical Science

A. PROJECT TITLE

The relationship between Body Mass Index (BMI) and functional capacity in prepubescent children.

B. RATIONALE

The number of overweight individuals in the Australian community has steadily increased in recent years. Whereas there has been significant study into the effects of this increased body weight and associated health risks, limited research has been conducted into the effects of increased body weight on the ability to perform daily activities (functional capacity), particularly in children. It is therefore the aim of this study to investigate the effects of increased body weight on functional capacity in prepubescent children in the Wollongong district.

C. PROJECT OBJECTIVES

The purpose of this study is to determine whether a relationship exists between body size and the capacity of prepubescent children to perform tasks (involving strength and flexibility), lower limb alignment or foot shape.

D. TEST PROCEDURE

For this study your child will:

a. have his/her weight and height recorded privately,
b. be required to perform strength and flexibility tasks, which will be observed and recorded. The strength tasks will involve your child standing up from a chair (recorded on videotape), jumping for height, throwing a ball for distance, and pushing and pulling an arm strength device (made especially for children). The flexibility task will involve your child reaching to touch their toes.
c. have the image of his/her legs recorded on slide film to allow assessment of limb alignment,
d. have their footprint recorded to allow assessment of foot contours.

The total time involved will be approximately 20 minutes and will be conducted at a time convenient to your child’s classroom teacher.
Children will be required to wear their usual sports uniform. All tasks will be performed without shoes and socks.

E. RISKS AND DISCOMFORTS

As this study involves your child performing simple tasks often repeated in daily living there are minimal risks involved. However, your child will not be required to perform any movements about which he/she does not feel comfortable.

F. ENQUIRIES

Questions concerning procedures and/or rationale used in this investigation are welcome at any time. Please ask for clarification of any point which you feel is not explained to your satisfaction. Your initial contact person is the investigator conducting this project, Diane Riddiford: 042 21 3881 or 015 864677. Subsequent enquiries may be directed to Julie Steele (Supervising Lecturer, Department of Biomedical Science, University of Wollongong: 042 213881) or Professor Len Storlien, (Head, Department of Biomedical Science, University of Wollongong: 042 213881). Any enquiries regarding the conduct of this research may be directed to the Secretary of the University of Wollongong Human Research Ethics Committee: 042 214457.

G. FREEDOM OF CONSENT

Participation in this project is entirely voluntary. Subjects are free to withdraw consent before or during the experiment. In the latter case such withdrawal of consent will be at the time specified by your child. Participation, or withdrawal of consent, will not influence your child’s schooling.

H. CONFIDENTIALITY

All results of this study will be treated with absolute confidentiality. Subjects will be identified in the resultant reports or publications by the use of subject codes only.
Ms Diane Riddiford  
University of Wollongong  
Northfields Avenue  
Wollongong 2522

5th July

Mr John Rock  
Balgownie Primary School  
Balgownie Rd.  
Balgownie 2519

Dear Sir

I am a postgraduate student studying for an Honours Masters degree in Biomedical Science at the University of Wollongong. Prior to returning to study I taught in both primary and secondary schools as a Physical Education/English teacher. A requirement of my current degree is to complete a major research study. The topic for my thesis is titled the “Relationship between Body Mass Index (BMI) and functional capacity in prepubescent children”.

The number of overweight individuals in the Australian community has steadily increased in recent years. Whereas there has been significant study into the effects of this increased body weight and associated health risks, limited research has been conducted into the effects of increased body weight on the ability to perform daily activities (functional capacity), particularly in children. It is, therefore, the aim of this study to investigate the effects of increased body weight on functional capacity in prepubescent children in the Wollongong district.

I have received approval from both the University’s Human Research Ethics Committee and the NSW Department of Education (please see letters attached) to conduct the above study of Grade 3 students from 20 schools in the Wollongong district.

Balgownie Primary School is one of the 20 randomly selected schools in the district. I therefore request permission for your students to participate in the study. Please find enclosed a copy of the Information Package and Informed Consent Form detailing the procedure for consenting students.

To ensure privacy, a testing area will need to be set up within the school building, separate to the participating student’s classroom. The duration of the testing will
depend on the number of Grade 3 students in your school. Each student will be tested for approximately 20 minutes with students tested in groups. The process will be ongoing, as students finish they will return to their classroom. The classroom teacher will only be required to assist with the movement of students to and from the testing area.

All findings of the study will be issued upon the studies completion.

I will contact you in the near future to discuss any inquiries you may have and your schools participation in the study. Thank you for considering my request. We believe this study is very important because it will provide necessary information which does not currently exist, information which may subsequently assist in reducing the prevalence of overweight children.

Yours sincerely

[Signature]
Appendix C

Subject Information Package

University of Wollongong
Department of Biomedical Science

A. PROJECT TITLE

The relationship between Body Mass Index (BMI) and functional capacity in prepubescent children.

B. RATIONALE

The number of overweight individuals in the Australian community has steadily increased in recent years. Whereas there has been significant study into the effects of this increased body weight and associated health risks, limited research has been conducted into the effects of increased body weight on the ability to perform daily activities (functional capacity), particularly in children. It is therefore the aim of this study to investigate the effects of increased body weight on functional capacity in prepubescent children in the Wollongong district.

C. PROJECT OBJECTIVES

The purpose of this study is to determine whether a relationship exists between body size and the capacity of prepubescent children to perform tasks (involving strength and flexibility), lower limb alignment or foot shape.

D. TEST PROCEDURE

For this study your child will:

a. have his/her weight and height recorded privately,
b. be required to perform strength and flexibility tasks, which will be observed and recorded. The strength tasks will involve your child standing up from a chair (recorded on videotape), jumping for height, throwing a ball for distance, and pushing and pulling an arm strength device (made especially for children). The flexibility task will involve your child reaching to touch their toes.
c. have the image of his/her legs recorded on slide film to allow assessment of limb alignment,
d. have their footprint recorded to allow assessment of foot contours.

The total time involved will be approximately 20 minutes and will be conducted at a time convenient to your child’s classroom teacher.
Children will be required to wear their usual sports uniform. All tasks will be performed without shoes and socks.

E. RISKS AND DISCOMFORTS

As this study involves your child performing simple tasks often repeated in daily living there are minimal risks involved. However, your child will not be required to perform any movements about which he/she does not feel comfortable.

F. ENQUIRIES

Questions concerning procedures and/or rationale used in this investigation are welcome at any time. Please ask for clarification of any point which you feel is not explained to your satisfaction. Your initial contact person is the investigator conducting this project, Diane Riddiford: 042 21 3881 or 015 864677. Subsequent enquiries may be directed to Julie Steele (Supervising Lecturer, Department of Biomedical Science, University of Wollongong: 042 213881) or Professor Len Storlien, (Head, Department of Biomedical Science, University of Wollongong: 042 213881). Any enquiries regarding the conduct of this research may be directed to the Secretary of the University of Wollongong Human Research Ethics Committee: 042 214457.

G. FREEDOM OF CONSENT

Participation in this project is entirely voluntary. Subjects are free to withdraw consent before or during the experiment. In the latter case such withdrawal of consent will be at the time specified by your child. Participation, or withdrawal of consent, will not influence your child's schooling.

H. CONFIDENTIALITY

All results of this study will be treated with absolute confidentiality. Subjects will be identified in the resultant reports or publications by the use of subject codes only.
Informed Consent Form

University of Wollongong
Department of Biomedical Science

THE RELATIONSHIP BETWEEN BODY MASS INDEX (BMI) AND FUNCTIONAL CAPACITY IN PREPUBESCENT CHILDREN.

The researchers conducting this project support the principles governing both the ethical conduct of the research, and the protection at all times of the interests, comfort and safety of subjects. This form and the accompanying Subject Information Package are given to you for your own protection. They contain a detailed outline of the experimental procedures, and the possible risks. Your signature below indicates:

1. You have received the Subject Information Package;
2. You have read its contents;
3. You have been given the opportunity to discuss the contents with the researcher prior to commencement of the experiment;
4. You clearly understand these procedures and possible risks;
5. You voluntarily agree for your child to participate in the project; and
6. Your child may withdraw consent and discontinue participation at any time without jeopardising his/her schooling.

Any concerns, complaints, or further questions may be directed initially to the investigator conducting this project, Diane Riddiford: 042 21 3881 or 015 864677. Subsequent enquiries may be directed to Julie Steele (Supervising Lecturer, Department of Biomedical Science, University of Wollongong: 042 213881), or Professor Len Storlien, (Head, Department of Biomedical Science, University of Wollongong: 042 213881). Any enquiries regarding the conduct of this research may be directed to the Secretary of the University of Wollongong Human Research Ethics Committee: 042 214457.

I freely and voluntarily agree for my child to participate as a subject in this study titled “The relationship between body mass index (BMI) and functional capacity in prepubescent children”.

Parent’s Surname: ___________________ Given Name:_____________________
Address: _________________________________________________________________
____________________________________________________________
Phone: __________________
Child’s Surname:_____________________ Given Name: _______________
Parent’s signature: _________________________ Date: _____/_____/199_
Sample Letter

Ms Diane Riddiford
University of Wollongong
Northfields Avenue
Wollongong 2522

9th August 1996

Dear Parent/Guardian

I am a postgraduate student studying for an Honours Masters degree in Biomedical Science at the University of Wollongong. Prior to returning to study I taught in both primary and secondary schools as a Physical Education/English teacher. A requirement of my current degree is to complete a major research study. The topic for my thesis is titled the “Relationship between Body Mass Index (BMI) and functional capacity in prepubescent children”.

I have received approval from both the University’s Human Research Ethics Committee and the NSW Department of Education to conduct the above study of Grade 3 students from schools in the Wollongong district.

Dapto Primary School has been randomly selected as one of these schools with students being tested on the 22nd of August. Please find enclosed a copy of the Subject Information Package and Informed Consent Form detailing the procedure for consenting students.

Children will be required to wear their sports uniform. Could girls please wear pant shorts, or similar, and boys wear shorts.

I hope your child will be able to participate. I believe this study is very important because it will provide necessary information which does not currently exist, information which may subsequently assist in reducing the prevalence of overweight children.

Yours sincerely

S. Riddiford
Appendix D

Prescribed Warm Up

All children followed a prescribed warm up procedure before the flexibility, power and strength tests. Due to the age of the subjects it was necessary to implement age appropriate warm up activities. These activities included:

- march on the spot like a soldier
- march on the spot like a soldier this time wearing REALLY heavy boots
- climb up an imaginary rope
- give your legs a big hug
- swim around an imaginary pool, first breaststroke and now freestyle
- squash an imaginary dead bug between your hands (at chest level)
- stretch up as tall as a tree
- bob down as small as a mouse
- jump up as high as you can
- walk around like a duck (children encourage to ‘quack’ like a duck too)
Appendices

Appendix E

Upper Limb Static Strength Test - Tensiometer

Technical Specifications:

1. Winston Bridge configuration strain gauge, S-type load cell designed for recording compression and tension (AND Co. Ltd., LC1205)

2. Maximum capacity: 200 kg (maximum digital display: 99.9 kg)

3. Accuracy: ± 100 g

4. Power source: 2 x 9 volt batteries

5. Hand grip weight: 900 g
Appendix F

Sample Footprints

Female aged 8 years, BMI = 16.7

Female aged 8 years, BMI = 22.8