Obesity the new childhood disability?

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Summary

This review addresses the impact of obesity on paediatric physical functioning utilizing the World Health Organization International Classification of Functioning, Disability and Health Framework (ICF). The ICF encompasses functioning (as it relates to all body functions and structures), activities (undertaking a particular task) and participation (in a life situation) with disability referring to impairments in body functions/structures, activity restrictions or participation limitations. Electronic databases were searched for peer-reviewed studies published in English prior to May 2009 that examined aspects of physical functioning in children (≤18 years). Eligible studies (N = 104) were ranked by design and synthesized descriptively. Childhood obesity was found to be associated with deficits in function, including impaired cardiorespiratory fitness and performance of motor tasks; and there was some limited evidence of increased musculoskeletal pain and decrements in muscle strength, gait and balance. Health-related quality of life and the subset of physical functioning was inversely related to weight status. However, studies investigating impacts of obesity on wider activity and participation were lacking. Further research utilizing the ICF is required to identify and better characterize the effects of paediatric obesity on physical function, activity and participation, thereby improving targets for intervention to reduce disability in this population.

Keywords: Body mass index, function, ICF, impairment.

obesity reviews (2009)

Introduction

Since the 1980s there has been a sharp increase in the prevalence of paediatric obesity with recent figures from developed countries suggesting that, based on the International Obesity Task Force (IOTF) Criteria (1), approximately 6–8% of 2–18 year olds are obese (2–5). While the cardiovascular and metabolic consequences of obesity have been studied extensively (6,7), less attention has been paid to investigating the impact of obesity on physical functioning and disability. It is becoming increasingly apparent from the adult literature that obesity is associated with reduced physical functioning and disability (8–10); however, paediatric literature in this area is limited.

International classification of disability and functioning

In an attempt to characterize the disability experience linked to a given health condition, the World Health Organization (WHO) developed the International Classification of Functioning, Disability and Health Framework (ICF) (Fig. 1) (11). Within this framework, the term functioning is a neutral concept that encompasses all physiological body functions and structures (e.g. neuromusculoskeletal functions, pain, etc.), activities (i.e. undertaking a particular task) and participation (i.e. in a life situation). The term disability refers to impairments in body functions/structures, activity restrictions or participation limitations. The functioning of an individual is the result of complex interactions between any given health condition, body
and colleagues (19) found a weak inverse relationship between knee extensor (KE) endurance and BMI (i.e. absolute muscle strength and body mass index (BMI) (13–15, 17). Almuzaini et al. (16, 17) found a moderate positive relationship between muscle strength and body mass resulting from excessive body fat (24), rather than to any difference in the quality of muscle tissue. This is supported by Blimkie et al. (13, 14) who found that obese boys exhibited reduced motor unit activation during maximal strength testing compared with non-obese boys (14), despite no differences in electrically evoked KE torques (13). Indeed, the findings of Blimkie et al. (13, 14) and studies reporting no differences in muscle strength after normalizing for FFM (17, 24) suggest that limitations in relative strength are more likely due to reduced motivation to express maximal strength or alternatively, to a mismatch between muscle strength and body mass resulting from excessive body fat (24), rather than to any difference in the quality of muscle tissue.

However, data on the effect of weight status on lower limb muscle function are somewhat limited by the fact that of the eight studies identified all were classified as providing lower quality evidence (i.e. level III-3 case–control or level IV). Relative strength are more likely due to reduced motivation to express maximal strength or alternatively, to a mismatch between muscle strength and body mass resulting from excessive body fat (24), rather than to any difference in the quality of muscle tissue.

Methods
A systematic search strategy (Table 1) was used to identify literature for this review. Studies identified in the search were classified according to the Australian National Health and Medical Research Council Evidence Hierarchy (12) (Table 2) as providing level I, II, III-1, III-2, III-3 or IV evidence, whereby level I represents the highest level of evidence (e.g. systematic reviews of level II studies such as randomized controlled trials or prospective cohort studies) and level IV the lowest level of evidence (e.g. case series or cross-sectional studies). To synthesize eligible literature, a descriptive critical analysis of studies was completed, with key features summarized into tables (Tables 3–7).

Body functions
Lower limb muscle function
In relation to lower limb muscle function, in general the literature indicated that obese children had similar (13–15) or higher absolute muscle strength/power compared with non-obese children (16, 17) (Table 3), but lower relative values (i.e. per unit body mass) (13–15, 17). Almuzaini et al. (18) found a moderate positive relationship between absolute muscle strength and body mass index (BMI) ($r = 0.58–0.69$) and a weaker but significant inverse relationship between knee extensor (KE) endurance and BMI ($r = -0.34$). Similarly, a longitudinal study by Armstrong and colleagues (19) found a weak inverse relationship between skin-folds and cycling peak power. In contrast, Grund et al. (20) found no relationship between knee flexor (KF)/KE strength and weight status.

The findings of higher absolute muscle strength/power in obese compared with non-obese children in some studies (16, 17) could be explained by the constant loading of the musculature due to a larger body mass that may impose a ‘training effect’. This premise has support from research indicating that obese children have higher absolute fat-free mass (FFM) (17, 20). However, relative strength/power is more important for activities which require people to move their own body mass and while the majority of studies indicate that relative strength/power is lower in obese compared with non-obese children, controversy exists regarding the most appropriate scaling method to enable comparisons between individuals of differing body size (21). Most authors have used ratio standards (see Table 3), whereby strength/power is divided by some measure of body size (e.g. mass, FFM), although this method assumes a linear relationship between variables which is not always the case (21, 22). Consequently, some studies have used allometric scaling (21–23), whereby strength is divided by a measure of body size to the power of a specific scaling exponent, although agreement around the most appropriate exponent for children is lacking (17, 22). Alternatively, some studies have used a measure of body size as a covariate in analyses to control statistically for any differences (17).

When correcting muscle strength/power for FFM or muscle cross-sectional area using ratio, allometric or covariate methods, most studies have reported no differences between obese and non-obese children (13, 14, 17, 24) (Table 3), although one study (20) reported that the weakest children had the highest absolute body mass, fat mass (FM) and FFM. This latter finding might be explained by reduced motivation to provide a maximal effort during strength testing in obese children compared with controls rather than to any difference in the quality of muscle tissue. This is supported by Blimkie et al. (13, 14) who found that obese boys exhibited reduced motor unit activation during maximal strength testing compared with non-obese boys (14), despite no differences in electrically evoked KE torques (13). Indeed, the findings of Blimkie et al. (13, 14) and studies reporting no differences in muscle strength after normalizing for FFM (17, 24) suggest that limitations in relative strength are more likely due to reduced motivation to express maximal strength or alternatively, to a mismatch between muscle strength and body mass resulting from excessive body fat (24), rather than to any difference in the quality of muscle tissue.
## Table 1 Search methods

<table>
<thead>
<tr>
<th>Key concepts</th>
<th>Search terms (combined using 'OR', wildcards used where available)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obesity</td>
<td>obese, obesity, overweight, adipose, BMI, 'body mass index', fat, fatness, 'weight status'</td>
</tr>
<tr>
<td>Child</td>
<td>child, children, adolescent, youth, pediatric, paediatric, adolescence, girls, boys</td>
</tr>
<tr>
<td>Strength</td>
<td>'muscle strength', torque, isometric, isokinetic, Kincom, Cybex, dynamometer, dynamometry, 'muscle weakness', muscle, quadriceps, 'knee flexion', 'knee flexors', 'knee extension', 'knee extensors', Biodex, concentric, eccentric</td>
</tr>
<tr>
<td>Pain</td>
<td>pain, painful, discomfort, noxious, ‘musculoskeletal pain’, ‘low back pain’</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Search Databases</th>
<th>All searches</th>
</tr>
</thead>
<tbody>
<tr>
<td>PubMed, Medline</td>
<td>*Limits set: English, human, all children 0–18, type of article, published after 1986. *General inclusion criteria: Examined children (0–18 years), looked at relationship/differences in the key concept(s) by weight status. *General exclusion criteria: Did not assess weight status OR looked at relationship/differences in the key concept(s) by weight status. *Included adults (≥19 years), focused on other health conditions, type of article, *exercise interventions.</td>
</tr>
<tr>
<td>1 and 2 and 3, 1 and 3</td>
<td>+Sport Discuss, OVID, CINAHL, Google Scholar</td>
</tr>
<tr>
<td>1 and 2 and 4, 1 and 2</td>
<td>+OVID, CINAHL, Google scholar, AMED, Embase</td>
</tr>
<tr>
<td>6, 6 and 1</td>
<td>+Embase, AMED, Google Scholar</td>
</tr>
<tr>
<td>1 and 2 and 5, 5</td>
<td>+Sport Discuss, OVID, CINAHL, Google Scholar, Embase</td>
</tr>
<tr>
<td>7, 7 and 2, 7 and 1</td>
<td>+CINAL, Psych info, psych articles, AMED, Google Scholar, Embase</td>
</tr>
<tr>
<td>9 and 1 and 2, 9 and 1</td>
<td>+Web of science, CINAHL</td>
</tr>
</tbody>
</table>

*Reference lists were hand searched and database auto-alerts set-up where available.

*Where database allows.
*Included clinical trial, meta-analysis, systematic review, randomized controlled trial, evaluation study, comparative study, controlled clinical trial.
*Key concepts were: obesity, child, strength, field-based tests, CRF, gait & balance, pain, HRQOL, disability activity & participation limitation.
**At enrolment.
*Excluded abstracts, dissertations, non-English, expert opinions, narrative reviews, editorials, case studies.
**Physical activity/exercise intervention studies were excluded as it would not be possible to differentiate if functional gains were due to the exercise, or improvements in weight status, with the exception of studies statistically investigating these relationships.

CRF, cardiorespiratory fitness; HRQOL, health-related quality of life; SLS, Single leg stance.
<table>
<thead>
<tr>
<th>Level</th>
<th>Intervention</th>
<th>Diagnostic accuracy</th>
<th>Prognosis</th>
<th>Aetiology</th>
<th>Screening intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>A systematic review of level II studies</td>
<td>A systematic review of level II studies</td>
<td>A systematic review of level II studies</td>
<td>A systematic review of level II studies</td>
<td>A systematic review of level II studies</td>
</tr>
<tr>
<td>II</td>
<td>A randomized controlled trial</td>
<td>A study of test accuracy with: an independent, blinded comparison with a valid reference standard, among consecutive persons with a defined clinical presentation</td>
<td>A prospective cohort study</td>
<td>A prospective cohort study</td>
<td>A randomized controlled trial</td>
</tr>
<tr>
<td>III-1</td>
<td>A pseudorandomized controlled trial (i.e. alternate allocation or some other method)</td>
<td>A study of test accuracy with: an independent, blinded comparison with a valid reference standard among non-consecutive persons with a defined clinical presentation</td>
<td>All or none</td>
<td>All or none</td>
<td>A pseudorandomized controlled trial (i.e. alternate allocation or some other method)</td>
</tr>
<tr>
<td>III-2</td>
<td>A comparative study with concurrent controls: a non-randomized experimental trial, cohort study, case–control study, interrupted time series with a control group</td>
<td>A comparison with reference standard that does not meet the criteria require for Level II and III-1 evidence</td>
<td>Analysis of prognostic factors amongst persons in a single arm of a randomized controlled trial</td>
<td>A retrospective cohort study</td>
<td>A comparative study with concurrent controls: non-randomized experimental trial, cohort study, case–control study</td>
</tr>
<tr>
<td>III-3</td>
<td>A comparative study without concurrent controls: historical control study, two or more single arm study, interrupted time series without a parallel control group</td>
<td>Diagnostic case–control study</td>
<td>A retrospective cohort study</td>
<td>A case–control study</td>
<td>A comparative study without concurrent controls: historical controls, two or more single arm study</td>
</tr>
<tr>
<td>IV</td>
<td>Case series with either post-test or pre-test/post-test outcomes</td>
<td>Study of diagnostics yield (no reference standard)</td>
<td>Case series, or cohort study of persons at different stages of disease</td>
<td>A cross-sectional study or case series</td>
<td>Case series</td>
</tr>
</tbody>
</table>

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### Table 3 Lower limb strength and weight status in children

<table>
<thead>
<tr>
<th>Reference</th>
<th>Author, year, design, evidence level</th>
<th>Subjects*</th>
<th>Obesity definition, reference data</th>
<th>Outcomes</th>
<th>Absolute strength higher in OB?</th>
<th>Strength lower in OB?</th>
<th>Strength &amp; weight status related?</th>
<th>Body size correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>(24)</td>
<td>Maffiuletti 2008, CC, III-3</td>
<td>10 SOB, 10 non-OB males, 13–17 years</td>
<td>SOB BMI &gt; 97%</td>
<td>BMI, Tanner, FFM (BI), Peak IK KE T, KE fatigue (Cybex)</td>
<td>Yes (IK KE T)</td>
<td>–</td>
<td>No difference</td>
<td>–</td>
</tr>
<tr>
<td>(18)</td>
<td>Almuzaini 2007, CS, IV</td>
<td>44 boys, 11–19 years</td>
<td>–</td>
<td>BMI, SF, Peak IK KE &amp; KF T, IK KE endurance (Cybex)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>Yes – BMI &amp; strength ((r = 0.58–0.69))</td>
</tr>
<tr>
<td>(17)</td>
<td>Duche 2002, CC, III-3</td>
<td>44 OB, 50 non-OB, ~14 years</td>
<td>OB BMI &gt; 97%, French</td>
<td>DXA (OB), SF (non-OB), BMI, CPP</td>
<td>Yes</td>
<td>Yes</td>
<td>No difference</td>
<td>Yes – CPP dependent on BF in OB</td>
</tr>
<tr>
<td>(19)</td>
<td>Armstrong 2001, long., II</td>
<td>747, 10–11 years</td>
<td>–</td>
<td>SF, BMI, CPP, Tanner</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>Yes – mass explains CPP ((r=0.88)), SF &amp; CPP ((r=0.16))</td>
</tr>
<tr>
<td>(20)</td>
<td>Grund 2000, CC, III-3</td>
<td>88, 4–11 years</td>
<td>OB &gt; 97%, German</td>
<td>BMI, BI, KE + KF strength (CT)</td>
<td>Weakest group had higher BM/FM</td>
<td>–</td>
<td>–</td>
<td>No</td>
</tr>
<tr>
<td>(14)</td>
<td>Blimkie 1990, CC, III-3</td>
<td>10 non-OB, 11 OB boys, 15–18 years</td>
<td>OB &gt; 30% BF</td>
<td>SF, Tanner, IM &amp; IK KE T (Cybex), EET, MUA, KE CSA</td>
<td>No difference</td>
<td>Yes</td>
<td>²No difference</td>
<td>–</td>
</tr>
<tr>
<td>(13)</td>
<td>Blimkie 1989, CC, III-3</td>
<td>11 non-OB, 13 OB boys, 9–13 years</td>
<td>OB &gt; 30% BF</td>
<td>SF, BMI, Tanner, R KE T (Cybex), EET, muscle CSA</td>
<td>No difference (KE)</td>
<td>Yes – KE</td>
<td>²No difference</td>
<td>–</td>
</tr>
</tbody>
</table>

* Unless otherwise stated subjects were of mixed gender.

²Normalized using muscle cross-sectional area.

BF, body fat; BI, bioelectrical impedance; BMI, body mass index; CC, case–control observational; CPP, cycling peak power; CS, cross-sectional; CSA, cross-sectional area; CT, computer tensiometry; DXA, dual energy X-ray absorptiometry; EET, electrically evoked torque; F, flexor; FFM, fat-free mass; HGS, handgrip strength; IK, isokinetic; IM, isometric; KE, knee extensor; KF, knee flexion; long., longitudinal study; MUA, motor unit activation; non-OB, non-obese; OB, obese; PA, physical activity; PWC 170, physical work capacity cycle ergometry 170 test; SF, skin-folds; SOB, severely obese; T, torque; V, voluntary; W, power.

Tanner, the Tanner scale has been widely used to assess pubertal development (134), as body composition is known to vary with puberty. The Tanner scale depicts five stages of sexual maturation, represented by drawings of pubic hair, scrotum and testes and breasts and has been validated as a self-assessment measure (135).

*Unless otherwise stated subjects were of mixed gender.

²Only included African-American girls.

²Normalized using muscle cross-sectional area.

BF, body fat; BI, bioelectrical impedance; BMI, body mass index; CC, case–control observational; CPP, cycling peak power; CS, cross-sectional; CSA, cross-sectional area; CT, computer tensiometry; DXA, dual energy X-ray absorptiometry; EET, electrically evoked torque; F, flexor; FFM, fat-free mass; HGS, handgrip strength; IK, isokinetic; IM, isometric; KE, knee extensor; KF, knee flexion; long., longitudinal study; MUA, motor unit activation; non-OB, non-obese; OB, obese; PA, physical activity; PWC 170, physical work capacity cycle ergometry 170 test; SF, skin-folds; SOB, severely obese; T, torque; V, voluntary; W, power.
### Table 4  Field-based fitness tests

<table>
<thead>
<tr>
<th>Reference</th>
<th>First author, year, design, evidence level</th>
<th>Subjects*</th>
<th>Obesity definition &amp; reference data</th>
<th>Outcomes</th>
<th>Performance &amp; weight status related?</th>
</tr>
</thead>
<tbody>
<tr>
<td>(35)</td>
<td>D’Hondt 2003, CS, IV</td>
<td>61 NW, 22 OW, 34 OB, 5–10 years</td>
<td>IOTF</td>
<td>BMI, Movement ABC, accelerometry</td>
<td>Yes</td>
</tr>
<tr>
<td>(18)</td>
<td>Almuzaini 2007, CS, IV</td>
<td>44 boys, 11–19 years</td>
<td>–</td>
<td>BMI, SF, vertical jump, sit &amp; reach</td>
<td>–</td>
</tr>
<tr>
<td>(53)</td>
<td>Bovet 2007, CS, IV</td>
<td>4599, 12–15 years</td>
<td>IOTF</td>
<td>BMI, shuttle runs, lateral &amp; vertical jumps, 40 m sprint, ball throw, sit-ups, push-ups</td>
<td>–</td>
</tr>
<tr>
<td>(54)</td>
<td>Brunet 2007, CS, IV</td>
<td>1140, 6–10 years</td>
<td>IOTF</td>
<td>BMI, WC, standing long jump, shuttle-run, sit-ups</td>
<td>–</td>
</tr>
<tr>
<td>(46)</td>
<td>Casajus 2007, CS, IV</td>
<td>1068, 7–12 years</td>
<td>IOTF</td>
<td>BMI, Eurofit, extra-curricular PA</td>
<td>Yes</td>
</tr>
<tr>
<td>(55)</td>
<td>Konst-Rock 2007, CS, IV</td>
<td>49 OB, 6–12 years</td>
<td>IOTF</td>
<td>BMI &gt; 97%</td>
<td>–</td>
</tr>
<tr>
<td>(34)</td>
<td>Maurer 2007, CS, IV</td>
<td>95, 7–9 years</td>
<td>IOTF</td>
<td>BMI, parent-proxy PA, heel rises</td>
<td>Yes</td>
</tr>
<tr>
<td>(56)</td>
<td>Modaff 2005, CS, IV</td>
<td>9415, 4–8 years</td>
<td>–</td>
<td>BMI, Modified Bavarian GM skills test</td>
<td>Yes</td>
</tr>
<tr>
<td>(36)</td>
<td>Fogelhorne 2007, CS, IV</td>
<td>2266, 15–16 years</td>
<td>IOTF</td>
<td>BMI, PA, endurance shuttle, sit-ups, sit &amp; reach, back-forth jumping, 5 jump, ball skills</td>
<td>Yes</td>
</tr>
<tr>
<td>(136)</td>
<td>Saxton 2006, CS, IV</td>
<td>306 OB, 10–17 years</td>
<td>Italian</td>
<td>Maganaria star test, BMI, birompedance, Tanner</td>
<td>–</td>
</tr>
<tr>
<td>(46)</td>
<td>Chen 2006, long., II</td>
<td>13005, 6–18 years</td>
<td>IOTF</td>
<td>Sit-ups, sit &amp; reach, test-step, BMI</td>
<td>Yes</td>
</tr>
<tr>
<td>(138)</td>
<td>Redfirdor-Harland 2006, CC, III-3</td>
<td>43 OB, 43 non-OB, 8.4 years</td>
<td>IOTF</td>
<td>Basketball throw, standing long jump, arm push &amp; pull, vertical jump, BMI</td>
<td>–</td>
</tr>
<tr>
<td>(47)</td>
<td>Telmakidis 2006, CS, IV</td>
<td>709, age 9–9 years</td>
<td>IOTF</td>
<td>BMI, Eurofit</td>
<td>Yes</td>
</tr>
<tr>
<td>(37)</td>
<td>Kim 2005, CS &amp; long., II</td>
<td>2987, 5–14 years</td>
<td>CDC BMI &gt; 95%</td>
<td>BMI, endurance shuttle run, curl-ups, sit &amp; reach, pull-ups, flexed arm hang,</td>
<td>–</td>
</tr>
<tr>
<td>(38)</td>
<td>Okley 2004, CS, IV</td>
<td>4363, grades 4.6–8,10</td>
<td>IOTF</td>
<td>Run, vertical jump, throw, catch, kick, strike, BMI, waist</td>
<td>Yes</td>
</tr>
<tr>
<td>(41)</td>
<td>Graf 2004, CS, IV</td>
<td>668, 1st grade</td>
<td>OB &gt; 97%</td>
<td>German</td>
<td>Yes</td>
</tr>
<tr>
<td>(137)</td>
<td>Graf 2004, CS, IV</td>
<td>344, mean age 6.8 years</td>
<td>OB &gt; 97%</td>
<td>German</td>
<td>Yes</td>
</tr>
<tr>
<td>(31)</td>
<td>Olds 2004, CS, IV</td>
<td>1480, aged 10–12 years</td>
<td>IOTF</td>
<td>BMI, 16 km walk/run</td>
<td>–</td>
</tr>
<tr>
<td>(32)</td>
<td>Delphine 2003, CS, III-3</td>
<td>3214 OB &amp; non-OB, 12–18 years</td>
<td>OB &gt; 90%</td>
<td>SF, BMI, Eurofit, PA Q</td>
<td>Yes</td>
</tr>
<tr>
<td>(39)</td>
<td>Westerstahl 2003, CS, IV</td>
<td>855, –16 years</td>
<td>IOTF</td>
<td>BMI, run-walk, vertical jump, 2-hand lift, sit-ups, bench press, back extensions</td>
<td>–</td>
</tr>
<tr>
<td>(138)</td>
<td>Chen 2002, CS, IV</td>
<td>444 65.2 boys, 433 555 girls, 7–18 years</td>
<td>OB &gt; 95%</td>
<td>GM, Kaestch test, sit &amp; reach test, sit-ups, BMI</td>
<td>Yes</td>
</tr>
<tr>
<td>(139)</td>
<td>Butterfield 2002, CS, IV</td>
<td>65, 5–8 years</td>
<td>–</td>
<td>GM, Motor Assessment Battery for Children &amp; Movement ABC</td>
<td>–</td>
</tr>
<tr>
<td>(44)</td>
<td>McKenzie 2002, long., II</td>
<td>202, 4–12 years</td>
<td>–</td>
<td>SF, SLS, lateral jumping, ball catch, PA interview</td>
<td>Yes</td>
</tr>
<tr>
<td>(30)</td>
<td>Fjodor 2000, CS, IV</td>
<td>75, 5–7 years</td>
<td>–</td>
<td>Eurofit, weight</td>
<td>–</td>
</tr>
<tr>
<td>(40)</td>
<td>Minick 2001, long., II</td>
<td>181, 13 years (4/27 years)</td>
<td>IOTF</td>
<td>SF, MOPER fitness test battery, PA interview</td>
<td>–</td>
</tr>
<tr>
<td>(39)</td>
<td>Reeves 1999, CS, IV</td>
<td>51, 5–6 years</td>
<td>–</td>
<td>BOTM short, ½ mile walk, PFTG, SF, BMI</td>
<td>–</td>
</tr>
<tr>
<td>(56)</td>
<td>Marshall 1997, CC, III-3</td>
<td>100 OB, 100 lean, grades 1–4</td>
<td>Marshall adiposity VRS</td>
<td>GM, SF, 20 m shuttle run</td>
<td>Yes (TGMD)</td>
</tr>
<tr>
<td>(28)</td>
<td>Malina 1996, CS, IV</td>
<td>6700 girls, 7–17 years</td>
<td>IOTF</td>
<td>SF, Eurofit, BMI, 7 PA recall</td>
<td>–</td>
</tr>
<tr>
<td>(48)</td>
<td>Pongpapai 1994, CS, IV</td>
<td>259, 6–12 years</td>
<td>OB &gt; 120% mass, Bangkok</td>
<td>SF, PGM, IU, BMI, 1.5 mile run, sit-ups &amp; reach, vertical jump, shuttle run, sit-ups</td>
<td>Yes</td>
</tr>
<tr>
<td>(42)</td>
<td>Chattejee 1993, CS, IV</td>
<td>629 boys, 9–18 years</td>
<td>–</td>
<td>GM &amp; movement test, walk/run, sit-ups, weight, sit &amp; reach, vertical jump, Maganaria stair test, 5-yard dash, shuttle run</td>
<td>Yes</td>
</tr>
<tr>
<td>(27)</td>
<td>Sallis 1993, CS, IV</td>
<td>526</td>
<td>–</td>
<td>BMI, PA, 24 h recall, accelerometer, FITNESSGRAM</td>
<td>Yes</td>
</tr>
<tr>
<td>(43)</td>
<td>Role 1989, CS, IV</td>
<td>4762, 6–16 years</td>
<td>–</td>
<td>SF, SCFT, 1 min sit-ups, sit &amp; reach, distance run</td>
<td>Yes</td>
</tr>
</tbody>
</table>

*Unless otherwise stated subjects were of mixed gender.

†Plate tapping was not significant, and sit & reach and leg lift were only significant in girls after controlling for mass and height.

‡Compared with German normative reference data, there was no difference in single leg stance and balance.

§Compared with German normative reference data, there was a difference in single leg stance and balance.

Not significant for sit and reach test, and/or control tests.

BF, body fat; BMI, body mass index; BOTM, Bruininks-Oseretsky Test of Motor Proficiency; CDC, Centre for Disease Control Prevention; CPP, cycling peak power; CS, cross-sectional study design; CSA, cross-sectional area; CT, computerized tomography; DNA, dual-energy X-ray absorptiometry; F, flexor; FFM, fat-free mass; GM, gross motor; GQSTM, General Sports Motor Test; HGB, hand grip strength; IK, isokinetic; IM, isometric; IOTF, International Obesity Task Force Criteria; KE, knee extensor; L, left; long., longitudinal study design; Movement ABC, Movement Assessment Battery for Children; MUA, motor unit activation; non-OB, non-obese; NW, normal weight; OB, obese; OR, odds ratio; OW, overweight; PA, physical activity; PFTG, Prudential Fitnessgram Test; Q, questionnaire; R, right; SCFT, South Carolina Fitness Test; SF, skin-folds; SLS, Single leg stance; TGMD, Test of Gross Motor Development; V, voluntary; VRS, visual rating scale; WC, waist circumference.
Table 5: Cardiorespiratory fitness and weight status in children

<table>
<thead>
<tr>
<th>Reference no</th>
<th>Author, year, design, evidence level</th>
<th>Subjects*</th>
<th>Obesity definition &amp; reference data</th>
<th>Outcomes</th>
<th>Absolute CRF higher in OB?</th>
<th>Fitness lower in OB?</th>
<th>Fitness &amp; weight status related?</th>
<th>Body size correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>(57) Drinkard 2007, CC, III-3</td>
<td>117 SOB, 43 non-OB, 12–17 years</td>
<td>OB &gt; 95%, CDC</td>
<td><strong>CE (VO2max), BMI, ADP</strong></td>
<td>No difference</td>
<td>–</td>
<td>VO2max 25% less in SOB</td>
<td>–</td>
<td>Ratio</td>
</tr>
<tr>
<td>(73) Berndtsson 2007, CS IV</td>
<td>219 OB, 11–16 years</td>
<td>IOTF</td>
<td><strong>CE (VO2max), BMI, PA interview</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes – BMI explained 45% of relative VO2max</td>
<td>–</td>
<td>Ratio</td>
</tr>
<tr>
<td>(140) Klasson-Heggebo 2006, CS, IV</td>
<td>4072, 9–15 years</td>
<td>OB &gt; 95%, ?CDC</td>
<td><strong>CE (Wmax/kg), SF, WC, BP, Tanner</strong></td>
<td>–</td>
<td>–</td>
<td>No – O2 deficit &amp; BMI</td>
<td>–</td>
<td>Ratio &amp; % change</td>
</tr>
<tr>
<td>(74) Reybrouck 2007, CC, III-3</td>
<td>219 OB, 11–16 years</td>
<td>IOTF</td>
<td><strong>CE (VO2max), BMI, PA interview</strong></td>
<td>–</td>
<td>–</td>
<td>Yes – VO2max</td>
<td>–</td>
<td>Cov. &amp; indep</td>
</tr>
<tr>
<td>(58) Norman 2005, CC, III-3</td>
<td>129 SOB, 34 non-OB, 12–17 years</td>
<td>OB &gt; 95%, CDC</td>
<td><strong>CE (VO2max, ULVO2), BMI, ADP, Tanner, 12 min walk/run</strong></td>
<td>No difference</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>(60) Lazzer 2005, CC, III-3</td>
<td>27 OB, 50 non-OB, 12–16 years</td>
<td>OB &gt; 97% French</td>
<td><strong>TT (VO2max), VE, SF, BSA</strong></td>
<td>Yes</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>(66) Ayub 2003, CC, III-3</td>
<td>9 OB, 9 lean, 11–18 years</td>
<td>IOTF</td>
<td><strong>TT (ET, W, VO2max), BI, SF</strong></td>
<td>Yes</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>(28) Malina 1995, CS, IV</td>
<td>6700 girls, 7–17 years</td>
<td>OB &gt; 97% German</td>
<td><strong>TT (Wmax/kg 2/3), BI, SF, BMI</strong></td>
<td>Yes</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>(142) Stewart 1995, CS, IV</td>
<td>53, 9–10 years</td>
<td>OB &gt; 50% OW, Tanner tables, OB &gt; 50% OW</td>
<td><strong>TT (W170), BMI, SF, PA interview</strong></td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>
## Table 5

<table>
<thead>
<tr>
<th>Reference no</th>
<th>Author, year, design, evidence level</th>
<th>Subjects*</th>
<th>Obesity definition &amp; reference data</th>
<th>Outcomes Absolute CRF higher in OB?</th>
<th>Fitness lower in OB?</th>
<th>Fitness &amp; weight status related?</th>
<th>Body size correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>(62)</td>
<td>Watanabe 1994, CC, III-3</td>
<td>13 OB, 24 non-OB, 12–15 years</td>
<td>OB &gt;20–20% %fat</td>
<td>TTT (VO2max, underwater weighing)</td>
<td>Yes – boys</td>
<td>Yes</td>
<td>No difference –</td>
</tr>
<tr>
<td>(48)</td>
<td>Pongprapai 1994, CS, IV</td>
<td>259, 6–12 years</td>
<td>OB&gt;120% OW Bangkok</td>
<td>TTT (VO2max, BMI)</td>
<td>–</td>
<td>Yes</td>
<td>–</td>
</tr>
<tr>
<td>(63)</td>
<td>Martes 1994, CC, III-3</td>
<td>14 OB, 8 non-OB, 9.5 years</td>
<td>Tanner tables, OB &gt;20% OW</td>
<td>TTT (VE), Tanner, SF</td>
<td>Yes – VO2max/VEmax</td>
<td>Yes</td>
<td>No difference –</td>
</tr>
<tr>
<td>(123)</td>
<td>Martes 1993, CC, III-3</td>
<td>23 OB, 17 non-OB, 9.3 years</td>
<td>Tanner tables</td>
<td>TT (VE), Tanner, SF</td>
<td>Larger VE response</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>(143)</td>
<td>Taylor 1991, CC, III-3</td>
<td>90 high fat, 93 low fat, 8–13 years</td>
<td>OB SF &gt; 90%</td>
<td>TTT (VO2max, VE O2 pulse), SF, BMI</td>
<td>Yes – VE, VO2max</td>
<td>Yes – VE &amp; VO2max/kg</td>
<td>–</td>
</tr>
<tr>
<td>(90)</td>
<td>Cooper 1990, CS, IV</td>
<td>18 OB, 9–17 years</td>
<td>OB &gt;120% OW</td>
<td>TTT (VO2max, VE VCO2 slope), weight</td>
<td>No difference</td>
<td>Yes</td>
<td>–</td>
</tr>
<tr>
<td>(70)</td>
<td>Zancanato 1989, CC, III-3</td>
<td>23 OB, 37 non-OB 9–14 years</td>
<td>OB &gt;20% OW Tanner tables</td>
<td>TTT (VE), Tanner, SF</td>
<td>No difference</td>
<td>Yes</td>
<td>No difference –</td>
</tr>
<tr>
<td>(64)</td>
<td>Elliott 1989, CC, III-3</td>
<td>16 OB, 17 non-OB, 9–18 years</td>
<td>OW/OB SF &gt; 85%</td>
<td>TTT (VO2max), SF</td>
<td>No difference</td>
<td>Yes</td>
<td>No difference –</td>
</tr>
<tr>
<td>(71)</td>
<td>Raybruck 1987, CC, III-3</td>
<td>15 OB, 257 non-OB, 4–16 years</td>
<td>TTT (VE), Tanner, SF, mass, PA Q</td>
<td>TTT (VT), Tanner, SF, mass, PA Q</td>
<td>Yes – VO2VT lower in OB</td>
<td>Yes – girls</td>
<td>–</td>
</tr>
<tr>
<td>(76)</td>
<td>Huttunen 1986, CC &amp; UCT, III-3</td>
<td>31 OB, 31 non-OB, 5.7–16.1 years</td>
<td>OB +2SD, Finnish</td>
<td>TTT (HR, RER, VO2max), SF, PA parents-proxy PA Q</td>
<td>No difference</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

*Subjects* refers to the number of obese and non-obese subjects and their age range.

**Tanner curves/studies.** The Tanner scale has been widely used to assess pubertal development (134), as body composition is known to vary with puberty. The Tanner scale depicts five stages of sexual maturation represented by drawings of pubic hair, scrotum and testes and breasts and has been validated as a self-assessment measure (135).* Unless otherwise stated subjects were of mixed gender.

**Maximal exercise testing.**

**Submaximal exercise testing.**

**Compared with reference data.**

**Curvilinear relationship.**

**Not significant when allometric scaling used.**

**Not significant when controlling for FFM.**

**Corrected for PA, height and weight.**

**In 12- and 13-year-old girls.**

**Acc., accelerometry; ADP, air displacement plethysmography; AT, anaerobic threshold; BI, bioelectrical impedance; BIA, bioimpedance; BMI, body mass index; BP, back pain; BSA, body surface area; CC, comparative control study (observational); CDC, Centre for Disease Control Prevention; CE, cycle ergometry; cov., covariate(s); CS, cross-sectional study; DLW, doubly labelled water; FFM, fat-free mass; FM, fat mass; HR, heart rate; IOTF, International Obesity Task Force Criteria; long., longitudinal study; LTVO2, lactate threshold; NCHS, National Centre for Health Statistics (USA); non-OB, non-obese; O2, oxygen pulse; OB, obese; OW, overweight; PA, physical activity; PA Q, physical activity questionnaire; PWC170, physical working capacity at HR of 170 bpm; RER, respiratory exchange ratio; SOB, severely obese; SF, skin-folds; TT, treadmill test; UUV02, oxygen uptake during unloaded cycling; VE, ventilator efficiency; VO2max, maximal oxygen uptake; WC, waist circumference; VAT, visceral adipose tissue; VT, ventilatory threshold; UCT, uncontrolled clinical trial study.**
<table>
<thead>
<tr>
<th>Reference</th>
<th>Author, year, design, evidence level</th>
<th>Subjects*</th>
<th>Obesity definition &amp; reference data</th>
<th>Outcomes</th>
<th>Pain recall period</th>
<th>Greater MS pain in OB?</th>
<th>Pain &amp; weight status related?</th>
</tr>
</thead>
<tbody>
<tr>
<td>(98) Bell 2007, CS, IV</td>
<td>104 OW/Ob, 73 non-Ob, 6–13 years</td>
<td>IOTF &amp; CDC</td>
<td>BMI, BMI z-score, MSE, puberty</td>
<td>Current</td>
<td>–</td>
<td>Yes – OR pain increases 2.54 per unit BMI z-score</td>
<td></td>
</tr>
<tr>
<td>(96) Massiero 2007, CS, IV</td>
<td>754, 13–15 years</td>
<td>–</td>
<td>1BMI, LBP Q, WA, activity Q</td>
<td>1 year</td>
<td>–</td>
<td>No (BMI)</td>
<td></td>
</tr>
<tr>
<td>(87) Morsen-Bondorp 2007, CS, IV</td>
<td>4813, 11–14 years</td>
<td>–</td>
<td>1BMI, Q BMI</td>
<td>Current, 1 month, 6 months, 1 year</td>
<td>–</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>(88) Chiang 2006, CS, IV</td>
<td>55, 11–14 years</td>
<td>–</td>
<td>1BMI, BMI, PA Q</td>
<td>2 weeks</td>
<td>No – LBP had lower BMI</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>(99) De sa Pinto 2006, CS, IV</td>
<td>49 OB, 47 non-OB, 7–14 years</td>
<td>NHNES I Ob &gt; 95%</td>
<td>BMI, MSE, pain Q</td>
<td>1 month</td>
<td>Yes – LBP &amp; LL</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>(100) Podeszwa 2006, CS, IV</td>
<td>50 Ob, 2–17 years</td>
<td>CDC Ob &gt; 95%</td>
<td>BMI, PCOC</td>
<td>–</td>
<td>–</td>
<td>Yes (box plot)</td>
<td></td>
</tr>
<tr>
<td>(101) Taylor 2006, CS, IV</td>
<td>277 OB, 12%, non-OB, 12.8 years</td>
<td>NHNES I Ob &gt; 95%</td>
<td>BMI, PCOC, DXA, Tanner, MSE, medical chart review</td>
<td>–</td>
<td>–</td>
<td>Yes – OR 4.04 in OB</td>
<td></td>
</tr>
<tr>
<td>(96) Poussa 2005, long., II</td>
<td>400, 10 years (3 years/22 at 22 years)</td>
<td>–</td>
<td>BMI, Q BMI</td>
<td>Current, 1 d, month, 1 year, lifetime</td>
<td>–</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>(90) Sher-Ness 2003, CS, IV</td>
<td>1126, 12–16 years,</td>
<td>–</td>
<td>CHQ, BP Q, intensity rating, pain diagram, BMI</td>
<td>1 month</td>
<td>Yes – BP had higher BMI</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>(91) Kovacs 2003, CS, IV</td>
<td>7361, 13–15 years</td>
<td>–</td>
<td>1BMI, Q, BMI, activity Q</td>
<td>Lifetime, 1 d &amp; current</td>
<td>Yes – OR 1.8 in OB boys</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>(92) Watson 2003, CS, IV</td>
<td>1446, 11–14 years</td>
<td>–</td>
<td>1BMI, Q, BMI, activity Q</td>
<td>1 month</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>(93) Szpalski 2002, long., II</td>
<td>287, 9–12 years</td>
<td>–</td>
<td>CHQ, BMI</td>
<td>Lifetime, onset</td>
<td>–</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>(102) Wake 2002, CS, IV</td>
<td>2863, 5–13 years</td>
<td>UK</td>
<td>1BMI, Q, BMI</td>
<td>Lifetime, 1 year</td>
<td>Yes – BMI at 7 years unrelated to LBP</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>(97) Lake 2000, long., II</td>
<td>11407, 14–33 years</td>
<td>OB &gt; 80%</td>
<td>CHQ, BMI, LBP Q</td>
<td>Lifetime, onset</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>(85) Salinen 1995, long., II</td>
<td>62, 15 years, 3 years/2</td>
<td>–</td>
<td>1BMI, Q, BMI, activity Q</td>
<td>Lifetime, 1 year</td>
<td>No – BMI does not predict LBP</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>(94) Salinen 1992, CS, IV</td>
<td>36 no LBP &amp; 38 LBP, 15 years</td>
<td>–</td>
<td>BMI pain questions, BMI</td>
<td>Past week</td>
<td>No difference in BMI between groups</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>(95) Harney 1999, CS, IV</td>
<td>1389, 13–16 years</td>
<td>–</td>
<td>BMI, LBP Q</td>
<td>Current, 1 d, 1 week, 1 year, lifetime</td>
<td>Yes – severe LBP more common if BMI &gt; 25</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>(103) Vahasarja 1996, CS, IV</td>
<td>856, 15 years</td>
<td>–</td>
<td>Postal knee pain Q, BMI, X-rays</td>
<td>No</td>
<td>No</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>(112) Nissinen 1994, long. II</td>
<td>859, 10.1 years, 3 years/2</td>
<td>BMI, Q BMI</td>
<td>Current, 1 d, 1 month, 1 year, lifetime</td>
<td>–</td>
<td>No – BMI not related LBP at 1 year</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tanner, The Tanner scale has been widely used to assess pubertal development (134), as body composition is known to vary with puberty. The Tanner scale depicts five stages of sexual maturation, represented by drawings of pubic hair, scrotum and testes and breasts and has been validated as a self-assessment measure (135).

*Unless otherwise stated subjects were of mixed gender.
†Assessed pain prevalence.
‡Assessed pain intensity.
§Assessed pain frequency.
* Included overweight participants in their non-OB group.
††Assessed pain recurrence.
BMI, body mass index; BP, back pain; CDC, Centre for Disease Control Prevention; CHQ, Child Health Questionnaire; CS, cross-sectional; DXA, dual energy X-ray absorptiometry; f/u, follow-up; IOTF, International Obesity Task Force Criteria; IWQOL, Impact of Weight on Quality of Life questionnaire; LBP, low back pain; LL, lower limb; long., longitudinal study; MRI, magnetic resonance imaging; MS, musculoskeletal; MSE, musculoskeletal examination; NHNES, National Centre for Health Statistics (USA), non-OB, non-obese; NW, normal weight; OB, obese; OR, odds ratio; OW, overweight; PA, physical activity; PODC, Paediatric Outcomes Data Collection Instrument; Q, questionnaire or questions; ROM, range of motion; SOB, severely obese; VAS, visual analogue scale.
Table 7: Balance, gait and weight status

<table>
<thead>
<tr>
<th>Reference</th>
<th>Author, year, design, evidence level</th>
<th>Subjects*</th>
<th>Obesity definition &amp; reference data</th>
<th>Outcomes</th>
<th>Deviated gait in OB?</th>
<th>Impaired balance in OB? Or balance &amp; weight status related?</th>
</tr>
</thead>
<tbody>
<tr>
<td>(113)</td>
<td>Colne 2008, CC, III-3</td>
<td>16 OB, 10 NW, –16 years</td>
<td>?</td>
<td>Force plate (CP), BMI</td>
<td>Yes – ↓DS &amp; swing phase, ↓progression velocities &amp; anticipatory phase with ↑velocity</td>
<td>Yes. Static: TCP sway, dynamic: LAP LOS</td>
</tr>
<tr>
<td>(116)</td>
<td>Nantel 2006, CC, III-3</td>
<td>10 OB, 10 non-OB, 8–13 years</td>
<td>OB &gt; 95% CDC</td>
<td>3D gait, FP, BMI</td>
<td>Yes – ↓SLS time, altered hip kinetics</td>
<td>–</td>
</tr>
<tr>
<td>(111)</td>
<td>Gushue 2005, CC, III-3</td>
<td>10 OB, 13 NW, –12 years</td>
<td>CDC OB &gt; 95%</td>
<td>3D gait, FP, BMI</td>
<td>Yes – ↑knee abd moment &amp; ↓peak KF, ↑variability knee kinetics</td>
<td>–</td>
</tr>
<tr>
<td>(66)</td>
<td>Volpe 2003, CC, III-3</td>
<td>9 OB, 9 non-OB boys, 11–18 years</td>
<td>–</td>
<td>DXA, BMI, PA Q, treadmill max test</td>
<td>Yes – ↑% VO2max when walking, mass explained 62–89% variance in energy cost</td>
<td>–</td>
</tr>
<tr>
<td>(121)</td>
<td>Goulding 2003, CC, III-3</td>
<td>25 OW/OB, 47 NW, boys 14.9 years</td>
<td>USA O!/OB &gt; 85%</td>
<td>DXA, BOTMP, SOT, LOS, PA Q</td>
<td>–</td>
<td>Yes – ↓ balance &amp; %fat (r = -0.3)</td>
</tr>
<tr>
<td>(117)</td>
<td>McGraw 2000, CC, III-3</td>
<td>10 OB, 10 non-OB, 8–10 years boys</td>
<td>CDC OB &gt; 95%</td>
<td>↑3D gait, standing &amp; tandem stance, FP</td>
<td>Yes – ↑DS &amp; stance time, ↑swing time, ↓speed</td>
<td>–</td>
</tr>
<tr>
<td>(115)</td>
<td>Habib 1998, CS, IV</td>
<td>180, 5–13 years</td>
<td>–</td>
<td>BOTMP, FRT, TUG, mass</td>
<td>–</td>
<td>Yes – mass &amp; balance (beta = -0.3)</td>
</tr>
<tr>
<td>(123)</td>
<td>Maffeis 1993, CC, III-3</td>
<td>23 OB, 17 non-OB, –9 years,</td>
<td>–</td>
<td>Treadmill walk/run</td>
<td>Yes – EE 12% higher in OB with faster walking</td>
<td>–</td>
</tr>
<tr>
<td>(122)</td>
<td>Hills 1993, CC, III-3</td>
<td>10 OB, 4 NW, 8–10 years</td>
<td>↑OB &gt; 95%</td>
<td>↑Gait EMG</td>
<td>No differences in EMG activity</td>
<td>–</td>
</tr>
<tr>
<td>(118)</td>
<td>Hills 1991a, CC, III-3</td>
<td>10 OB, 10 NW, 8–10 years</td>
<td>↑OB &gt; 95%</td>
<td>↑2D gait</td>
<td>Yes – ↑Tstance, ↓speed, asymmetry, ↑stride width</td>
<td>–</td>
</tr>
<tr>
<td>(119)</td>
<td>Hills 1991b, CC, III-3</td>
<td>10 OB, 4 NW, 8–10 years</td>
<td>↑OB &gt; 95%</td>
<td>↑2D gait</td>
<td>Yes – ↑Tstance, ↓cadence &amp; speed, asymmetry</td>
<td>–</td>
</tr>
<tr>
<td>(124)</td>
<td>Katch 1988, CS, IV</td>
<td>20 OB, –13 years</td>
<td>↑NCHS II, OB &gt; 178%</td>
<td>BMI, UW, treadmill walking</td>
<td>Yes – ↓efficiency with ↑walking speed</td>
<td>–</td>
</tr>
</tbody>
</table>

↓ – Decreased/slower/reduced; ↑ – increased/greater/longer.
*Unless otherwise stated subjects were of mixed gender.
1Walking at slow, fast and self-selected speeds.
2NHMRC Australian reference data.
2D, two dimensional; 3D, three dimensional; abd, abduction; AP, antero-posterior; BMI, body mass index; BOTMP, Bruininks-Oseretsky test of motor proficiency balance subset; CC, case–control observational study; CDC, Centre for Disease Control Prevention; CG, centre of gravity; CP, centre of foot pressure trajectory; CS, cross-sectional study; DS, double-limb support; DXA, dual energy X-ray absorptiometry; E, extension; EE, energy expenditure; EMG, electromyography; F, flexion; FP, force plate; FRT, functional reach test; KF, knee flexion; LOS, balance master limits of stability test; LOS, limits of stability; med/lat, medial/lateral; NCHS, National Centre for Health Statistics (USA); NHMRC, National Health and Medical Research Council of Australia; NW, normal weight; OB, obese; OW, overweight; PA, physical activity; PA Q, physical activity questionnaire; RSA, running speed agility; SLS, single leg stance; SOT, Equitest sensory organization test; TUG, timed up and go test; UW, underwater weighing; VO2, oxygen uptake; VO2max, maximal oxygen uptake.
IV cross-sectional) (13–15,17,18,20,24) except for one prospective study which was classified as level II (19) (see Table 3). Additionally, definitions of weight status varied between studies with some assessing body fat or skin-fold thicknesses (13–15,17,19) while others used BMI (18,20,24); none applied the IOTF criteria (1). Only four papers (13,14,19,24) considered the potential confounding impact of puberty on muscle function (25) and comparisons between studies were complicated by differing assessments/components of muscle function, including isokinetic and isometric peak KE torque, peak isokinetic KF torque, cycling peak power, KE endurance and electrically evoked muscle contractile properties (Table 3). Even where studies assessed common outcomes using the same dynamometer (14,18,24), test protocols varied due to a lack of any consensus around standardized dynamometry testing in children (26). Nevertheless, in general the data suggest that obese children have similar or higher absolute, but lower relative, muscle strength compared with non-obese children.

Field-based tests
Numerous studies have examined the impact of weight status on health-related physical fitness and motor skill competency, utilizing field-based tests (Table 4). Studies which compared obese children (or combined overweight/obese samples) with non-obese children all found that the former performed significantly worse in tasks requiring them to support or move their body mass (Table 4), which agrees with the findings of a number of studies which have reported weak to moderate inverse relationships between measures of weight status and performance in weight-bearing tasks (18,27–44) (Table 4). Similarly, flexibility (i.e. sit and reach test) and coordination (i.e. plate tapping, stick balance, etc.) were impaired in overweight/obese children compared with controls (28,36,42,45–48) (Table 4). Three studies (36,40,41) examined whether performance in field-based tests was impacted by physical activity levels and found that while increased physical activity levels may be associated with improved physical performance, this did not completely negate the detrimental effect of increased weight status. Minck et al. (40) (level II evidence) and Raudsepp et al. (41) (level IV evidence) used similar test batteries, and found persistent weak to moderate inverse relationships between physical performance and skin-folds after controlling for moderate/vigorous activity in multivariate analyses. Similarly, Fogelholm and colleagues (36) (level IV evidence) found that overweight participants performed more poorly than their lean counterparts irrespective of their physical activity levels, although interestingly they found stronger relationships between physical activity and performance ($\beta = 0.31–0.49$) than between overweight and physical performance ($\beta = -0.24–0.27$), suggesting that a lack of physical activity may be more important than the extent of overweight in predicting performance.

A limitation of the studies which have examined the impact of weight status on health-related physical fitness is that they have utilized self-report or parent-proxy methods to assess physical activity which can be subject to bias and reduced accuracy of recall (49,50). Additionally, most of these studies constitute lower level evidence (levels III-3 or IV), although some utilized very large sample sizes (28,31,32,36,37,43,45,51–54), therefore improving the generalizability of their findings. Importantly, four prospective studies (level II evidence) were located (37,40,44,46), two of which had relatively large samples ($>N = 2900$) (37,46). Almost all studies utilized BMI (see Table 4); some reported skin-fold thicknesses (18,28,40,41,43,44,45,52,55,56), whilst others only reported weight (30,42), without normalizing for height. This is an important limitation because height has a positive influence on physical performance (18). Notably, most studies did not consider the impact of puberty, which positively impacts physical performance in both boys ($r = 0.56–0.73$) and girls ($r = 0.24–0.46$) (25), although the relationship is weaker in girls. Despite these various limitations, the study findings are relatively consistent, but further research utilizing objective methods appears warranted.

Cardiorespiratory fitness
Studies which have examined cardiorespiratory fitness (CRF) and weight status in children suggest that it is unlikely that obese children have impaired absolute CRF, although some decrements may be present in severely obese adolescents (57,58). However, CRF relative to body mass is impaired and this is related to activity restrictions in walk/run performance, but the link between relative CRF and real-life participation restrictions remains unexplored.

Studies examining CRF and weight status in children were classified as either level III-3 or IV evidence, with the exception of one prospective study (40) (level II evidence) (Table 5). Maximal ($\text{VO}_{2\text{max}}$) or peak ($\text{VO}_{2\text{peak}}$) oxygen uptake were most commonly investigated (Table 5). However, many studies utilized submaximal testing protocols to predict $\text{VO}_{2\text{max}}$, which is less precise than direct measurement (59). Even where studies undertook maximal fitness testing, no consistent testing protocols or criteria for defining what constituted a valid maximal test were used (57,58,60–66). Furthermore, some studies used proxy measures of CRF such as endurance time, work performed, oxygen deficit and heart rate during submaximal exercise (Table 5), making it difficult to draw direct comparisons between findings. As with muscle function, controversy exists regarding correction for body size when evaluating impairments in CRF. For the most part, studies have used ratio standards, although allometric modelling (40,65) and
statistically controlling for FFM/height (58,61,67) or other body size-independent outcomes have also been used (Table 5). Other limitations have included the use of varying definitions of weight status, proxy measures of fitness and failure to assess pubertal development.

Despite the aforementioned limitations, moderate to strong inverse relationships between relative VO2max (per kilogram of body mass) and weight status were consistently reported indicating that fitness relative to body mass declines with increasing weight/BMI/fat (r = −0.49 to −0.843) (20,40,62,65,68,69) (Table 5). In contrast, when examining absolute VO2max (in litres per minute), most studies reported a positive relationship with weight status, indicating that absolute VO2max increased with weight status (r = 0.55–0.72) (61,68,69). Conversely, one prospective study (40) reported that absolute VO2max decreased with increasing skin-fold thickness (r = −0.4), although two of the four measurement points in this study occurred during adulthood. Similarly, Zanconato et al. (70) provided some evidence of a relationship between absolute VO2max and per cent overweight (r = −0.3), but this was not statistically significant, suggesting they were underpowered due to a small sample size (N = 60).

Many studies seeking to determine the effects of paediatric obesity on CRF have compared differences between obese and non-obese children. This research suggests that obese children have at least similar, and more often, higher absolute VO2max compared with their lean counterparts (20,57,58,60–66,70–76) (Table 5). However, despite a greater absolute VO2max, it has been consistently found that relative VO2max (per kilogram of body mass) is lower in obese compared with non-obese children (20,48,61–66,68,70–73,76,77) (Table 5). Studies have also normalized VO2max per kilogram of FFM, and in most cases have found no difference between obese and non-obese participants (20,60–64,72,75) (Table 5), suggesting that the higher absolute VO2max in obesity is most likely a function of the greater FFM. However, Drinkard et al. (57) found that VO2peak per kilogram of FFM was impaired by 25% in severely obese compared with non-obese adolescents, and Norman et al. (58) found that VO2max remained lower in severely obese adolescents compared with controls despite controlling for differences in FFM. It is unclear why there are discrepancies in the literature, but the majority of studies in this area support the proposition that the quality of FFM in terms of its ability to utilize oxygen does not differ between obese and non-obese children and the differences in both absolute and relative VO2max or VO2peak are due to differences in the quantities of FFM and body fat present.

As a result of the ongoing debate around normalization of CRF for body size, a number of authors have attempted to utilize measures of CRF that are independent of body size. For example, Reybrouck et al. (78) concluded that obese participants had reduced exercise capacity based on measurements of ventilatory threshold, which is proposed to represent the maximal aerobic exercise intensity that can be sustained for a prolonged period (79). In addition, Norman and colleagues (58) examined oxygen consumption during unloaded cycling (ULVO2), expressed as a percentage of VO2max and found that obese participants utilized a higher proportion of their cardiorespiratory reserve during unloaded cycling compared with non-obese participants. A similar study (80), which investigated the effect of obesity on VO2 reserve (VO2max – ULVO2), found that in lean children, VO2max increased whilst ULVO2 remained unchanged with increasing weight, resulting in an increase in VO2 reserve, whilst in obese children VO2 reserve remained unchanged with increasing weight, due to parallel increases in VO2max and ULVO2. The findings of these studies (58,80) appear to reflect the inefficiencies associated with additional lower limb fat tissue mass impacting on the energy cost of unloaded cycle exercise and indicate a progressive reduction in efficiency with increasing FM. Despite this, there are no widely accepted size-independent measures of CRF, so relative VO2max remains the most commonly reported indicator of CRF in both obese and non-obese populations.

There is evidence that engaging in moderate/vigorous physical activity increases CRF (81). Whilst a number of studies investigating weight status and CRF have also assessed physical activity levels, only one study (40) statistically corrected for physical activity levels, finding an inverse relationship between relative VO2max and adiposity (r = −0.2), suggesting that physical activity does not completely moderate the relationship between adiposity and CRF.

A small number of studies have examined the relationship between CRF and the ability, or inability, to undertake specific activities (i.e. activity restriction). Norman and colleagues (58) found that ULVO2 (expressed as a percentage VO2max) was inversely related to walk/run distance (r = −0.98) in severely obese adolescents. Similarly, VO2peak was related to walk/run capacity (r = 0.19–0.72) (58,82). However, no studies controlled for height which is positively related to physical performance (r = 0.45) (83).

Musculoskeletal pain

It has been proposed that obese children experience more musculoskeletal (MS) pain than healthy-weight children as a result of the increased loading and/or biomechanical deviations due to excessive FM. Such loading may be particularly detrimental during the periods of rapid growth and development that occur in childhood (84). While there is some evidence to suggest that obese children experience a higher prevalence of pain compared with non-obese children, the evidence is limited, and has not examined whether
the higher pain prevalence in obese children is associated with activity and participation restrictions.

Cross-sectional (level IV evidence) and longitudinal studies (level II evidence) have investigated the relationship between MS pain and weight status in children and adolescents (Table 6). Most cross-sectional studies used large sample sizes (~1000 to ~7500), which strengthens the generalizability of their findings, and the vast majority of studies investigated low back pain (85–97), with few examining overall MS pain (90,98–102). Thus, there is a paucity of evidence on which to base conclusions about weight status and any impact on lower limb or other forms of MS pain, other than low back pain.

Most pain research in children and adolescents has utilized self-report questionnaires, often containing only one or two specific questions about pain (Table 6). All of the literature has examined the presence of pain (prevalence or incidence), with few studies examining other aspects of pain such as intensity (86,90,95), frequency (85,90,95,99,102,103), or recurrence of episodes (91,97) and none have investigated the qualitative affective/emotional pain experience. Pain intensity assessments are particularly relevant in children and adolescents as higher intensity pain has been linked to functional limitations in the general paediatric literature (104–106). The pain recall periods used by authors to assess pain intensity have ranged from point assessments to lifetime prevalence/incidence despite evidence that the pain recall period used can influence the outcome. Whilst 72–83% of 3–17 year olds can accurately recall painful events after 1 and 6 weeks (107,108), accuracy declines to only 65% after 12 months (109). Accuracy of recall also appears to differ between pain modalities, with recall being better for acute than chronic pain (110). Thus, interpretation of pain outcomes in children should take account of the modality of the pain (acute or chronic) and the pain recall period.

Only five studies (Level III-3 and IV evidence) have specifically examined MS pain in obese children (98–102), reporting higher pain prevalence compared with non-obese children. Authors have found that obese children are approximately two to four times more likely to experience MS pain compared with healthy-weight children (98,101,102) (Table 6), although Wake et al. (102) only found this to be the case in obese boys. In contrast, Podeszwa et al. (100) only found a higher pain prevalence in obese girls and older children (≥11 years) when compared with normative reference data. De Sa Pinto et al. (99) found that obese children had double the prevalence of lower extremity pain compared to non-obese children. Notably, all studies were methodologically limited, with Taylor et al. (101) assessing pain retrospectively from medical charts and, like others, relying on poorly defined ‘physical examinations’ (98,99,101). Two studies used validated questionnaires (100,102), although one of these (100) only included children presenting to their orthopaedic clinic which is a likely source of bias. The other study (102) used the Child Health Questionnaire which only included one question evaluating pain frequency, hence offering limited insight into the pain experienced by children. Interestingly, some studies (95,96) reported biomechanical deviations in obese participants including knee recurvatum and valgus (100,101) which supports the hypothesis that obesity may induce biomechanical deviations which predispose to pain. Similarly, Gushue et al. (111) found that obese children had increased knee abduction moments during locomotion when compared with their lean counterparts, which could lead to overloading of the medial joint compartment, potentially causing progressive damage which would predispose the child to future pain development.

The majority of studies in this area examined back pain in general paediatric populations and found no relationship between weight status and low back pain (85–88,91–93,96,103,112). In particular, four prospective studies found that child/adolescent BMI did not predict low back pain incidence (85,96,97,112), although one of these studies (85) did find that adolescents with back pain were heavier, but they were also taller, hence the lack of relationship with BMI. Only one of these four studies (97) defined the weight status of participants as either overweight, obese or healthy and found no relationship between back pain and weight status, but the defined BMI cut-offs were lower than current IOTF definitions, meaning healthy-weight children would have been classified as overweight and overweight children would have been classified as obese. In contrast, some studies have reported that BMI is higher in participants with back pain (89,90,95), but their cross-sectional designs do not make it possible to establish whether the back pain was caused by a higher BMI, or whether having pain limited activity resulted in a higher BMI. In the remaining literature, it is unclear if obese children were included. Furthermore, even though some studies attempted to categorize weight status using BMI, without more accurate assessments of adiposity it will not be possible to determine whether a certain level of excess FM is associated with increased MS pain.

In summary, more research is needed to specifically examine the relationship between obesity and overall MS pain and in particular, lower limb pain, utilizing valid, multidimensional pain assessment tools that incorporate assessments of pain intensity and its relationship to functional limitations. There is an urgent need for research examining whether MS pain is associated with activity and participation restrictions in obese children.

### Balance and gait

It has been postulated that obesity may be associated with instability, deviations and inefficiencies in gait and balance...
activity might assist in maintaining balance. However, even cal activity levels is not clear. Intuitively, one may expect balance in obese children is mediated in any way by physi-
back to maintain balance (117). Whether the impaired
posterior and medio-lateral balance (113,117), particularly
when visual feedback has been compromised, suggesting
impairments in gait and impairments in gait have been reported in
children (113,114), and in general this is supported by the literature.
Twelve eligible studies examined the impact of weight
status/obesity on gait and postural control, consisting of
level III-3 and IV evidence, involving very small samples
of obese and lean children (N ≤ 26) in all but one
study (N = 128) (115) (Table 7). Postural stability has been
assessed both statically (e.g. bipedal stance) and dynami-
cally (e.g. unstable weight-bearing surface). While motion
analysis and force platforms have been used by some
authors to assess balance and gait (66,111,113,116–119)
(Table 7), most research has used field-based balance
assessments such as the Flamingo Balance Test from the
Eurofit Test Battery (120). Although studies using field-
based assessments have typically involved large samples
which increases generalizability (Table 4), they do not
provide insight into medio-lateral vs. antero-posterior
restrictions in postural control that are afforded by studies
using force platforms.

The majority of evidence suggests that postural stability,
in particular dynamic stability, may be impacted negatively
by obesity and/or increasing weight status in children
(Tables 4 and 7). Colne et al. (113) reported that under
static conditions postural sway was greater in obese com-
pared with lean children. In contrast, Goulding et al. (121)
reported no decrement in static balance in obese children,
although their comparative non-obese sample included
overweight children which may have attenuated any dif-
fferences between obese and lean participants. However,
in terms of dynamic stability, most research agrees that
obesity and/or increasing weight status has a negative
impact, particularly under novel/unfamiliar conditions
(30,52,113,115,117,121) (Tables 4 and 7), with the excep-
tion of one study (41) utilizing the Flamingo Balance
Test. Force-plate studies have reported impaired antero-
posterior and medio-lateral balance (113,117), particularly
when visual feedback has been compromised, suggesting
that obese children may be very dependent on visual feed-
back to maintain balance (117). Whether the impaired
balance in obese children is mediated in any way by physi-
cal activity levels is not clear. Intuitively, one may expect
that increased muscle strength associated with physical
activity might assist in maintaining balance. However, even
though Goulding et al. (121) found impaired dynamic sta-
bility in obese children, there were no differences in their
self-reported physical activity compared with controls.

Dynamic balance is important in terms of its contribu-
tion to gait and impairments in gait have been reported in
children with obesity (level III-3 and IV evidence, Table 7).
Multiple studies have reported kinematic (i.e. spatiotempo-
ral) deviations in gait in obese children (113,116–119),
with some authors interpreting this as a ‘slowing effect’
while others have attributed it to poor dynamic stability
(i.e. poor dynamic balance) (113). The deviations in gait
observed include: slower self-selected walking speeds,
shorter swing phase, longer stance phase, reduced single
limb support time, greater stride width and reduced step
length and frequency (113,117–119,122). There is also
evidence of overall gait asymmetry and variability in knee
kinetics (111,118,119) which would reduce efficiency,
despite altered hip kinetics which might attenuate some of
this efficiency loss (116). However, the alteration in hip
kinetics does not appear to completely balance the loss of
efficiency due to overall gait asymmetry and variability in
knee kinetics, as obese children have been shown to expend
more energy than lean children when walking at faster
speeds (66,123,124).

In summary, there is evidence to support the presence of
balance and gait deviations in obese children; however,
studies are few and draw findings from very small samples.
Furthermore, the potential confounding impact of physical
activity levels has not been addressed in any of these
studies. Whilst gait analysis is informative, it must be
remembered that the conditions under which it is per-
formed are not necessarily reflective of everyday life, and
clinical gait analysis may not reflect true functional mobi-
ity. These questions would be addressed by studies exam-
in ing whether decrements in balance or gait translate into
real-life functional limitations, but these studies are lacking
in the current literature.

Obesity and activity/participation limitations

While obesity is associated with multiple impairments in
body functions, it is important to examine the effect of
these impairments on activity (ability to undertake a spe-
cific task) and participation (engagement in a real-life situ-
tation), as these may impact on quality of life. Activity and
participation may be further qualified in terms of capacity
(i.e. ability to execute a task in a uniform or controlled
environment) and performance (i.e. what the person actu-
ally does in real-life situations), with the gap between
capacity and performance potentially reflecting the impact
of, or interaction with, environmental factors (125).

Activity restriction

Much of the research using field-based fitness tests (see
Table 4) has examined the capacity to perform specific
activities. However, many tasks within field-based test bat-
teries are highly specific (e.g. plate tapping, standing long
jump, etc.) and are not representative of common daily
activities undertaken by children. Nevertheless, in assess-
ments of walk/run activities, which are representative of
daily tasks, obese children exhibit capacity restrictions
(see Table 4 and reference (58)), which is not surprising,
given the additional mass they are required to move. For
example, Norman et al. (58) found that severely obese
adolescents covered 42% less distance than non-obese
children during a 12-min walk/run test. Riddiford-Harland et al. (126) also found that obese children had restrictions when moving from sit to stand, with 69% of children needing external assistance to complete the task. However, the seat height was very low (25% of participant stature) and it is not clear whether obese children have difficulty getting up from a more conventional height chair. While these studies provide evidence of difficulty in performing some basic daily activities, evidence relating to the effects of childhood obesity on the performance of other common functional daily tasks is lacking.

Participation limitations

There is a distinct lack of available research specifically examining participation limitations in obese children (i.e. within meaningful life situations). Whilst a large body of literature has examined physical activity behaviours in obese children, physical activity only represents a very small proportion of what a child does during their day and therefore such studies are not reflective of overall participation restrictions. In contrast, studies investigating health-related quality of life (HRQOL) (defined as physical, mental and social well-being related to a health condition (127)) have examined multiple components of activity and participation (128) and, to a much lesser extent, body functions. A review investigating the impact of weight status on HRQOL in children has already been published by the authors (129) and indicated that, in general, greater weight is associated with lower HRQOL. More specifically, there were strong inverse relationships between overall HRQOL and BMI and between physical functioning and BMI, with the physical function domain of HRQOL including assessments of engagement in activities of daily living. Other studies have also confirmed that obese individuals have impaired HRQOL and physical functioning compared with their lean counterparts (130,131), and that overall HRQOL and physical functioning are likely to improve with weight loss (132,133). It is worth noting that the physical functioning subset of the PedsQL™, which is the most commonly used paediatric HRQOL instrument, assesses a limited range of life areas and activities, therefore providing minimal insight into activity and participation restrictions in children with obesity.

Conclusion

It is apparent from the literature that, even in childhood, obesity is accompanied by functional impairments such as decrements in CRF relative to body mass and deficits in performance of body mass-dependent motor tasks (i.e. components of field-based fitness tests). A small number of studies reported a higher prevalence of MS pain in obese children although there was no evidence of low back pain associated with paediatric obesity. Impairments in knee strength relative to body mass and gait deviations have also been reported in obese children, but such findings are based on a limited number of studies with small sample sizes.

Obesity is also associated with activity restrictions and the literature indicates a negative impact on walk/run capacity, although impacts on other common daily activities are unclear. HRQOL studies suggest that increasing weight status is associated with poorer real-life physical functioning. However, HRQOL tools only provide limited insight; hence broader impacts on participation and functioning are not known.

Perhaps most importantly, those studies which have examined the effect of obesity on impairment have failed to investigate whether impairments in body functions translate into activity/participation restrictions; a flaw most likely related to a lack of consideration of the ICF framework. Future research should utilize international classifications of BMI to facilitate comparisons between studies, and endeavour to assess activity and participation restrictions, particularly within the context of the ICF framework, rather than just examining engagement in physical activity. This will provide a more meaningful evaluation of the effects of obesity on activity/participation. In particular, it is important to consider the impact of obesity on specific impairments in activity and participation as this may provide targets for clinical intervention to improve functioning in the short term whilst the more difficult and longer-term task of weight management is undertaken. Furthermore, by intervening in childhood, there may be an opportunity to improve functioning and disability before the onset of obesity-related degenerative MS changes that are prevalent in obese adults.

Conflict of interest statement

No conflict of interest was declared.

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