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POSTURAL BALANCE, ISOMETRIC TRUNK MUSCLE STRENGTH AND LOW BACK SYMPTOMS AMONG YOUNG ADULTS

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Abstract

Low back pain (LBP) is a significant health problem in all developed countries. The high prevalence of LBP in youth is a cause of concern because a link has been reported between LBP in adolescence and chronic LBP (CLBP) in adulthood. In order to prevent CLBP in adulthood potential protective factors in youth should be identified. The association between trunk muscle strength and LBP has been widely studied but the results are conflicting. The current knowledge on the role of postural balance in relation to LPB is even more controversial.

The aims of the thesis were to evaluate 1) the reproducibility of the inclinometric postural balance and maximal isometric trunk muscle strength measurements, 2) the association of low back symptoms with postural balance, trunk muscle strength, and cross-sectional area and fat content of extensor muscles, and 3) muscular fitness in relation to physical activity and television viewing.

The study population belongs to the 1986 Northern Finland Birth Cohort (NFBC 1986), originally consisting of 9,479 children with an expected date of birth between July 1, 1985 and June 30, 1986. A total of 874 subjects completed the physical examination at a mean age of 19 years. Of those who participated in the physical examination 554 subjects took part in magnetic resonance imaging (MRI) of the lumbar spine, including extensor muscles, at a mean age of 21 years.

Reproducibility of isometric trunk muscle testing was found to be comparable to other methods that are used to measure trunk muscle function. Low back symptoms were not associated with postural balance or trunk muscle strength. Neither was there an association between LBP and the cross-sectional area or fat content of the lumbar muscles. Trunk muscles were significantly stronger in those who participated in regular physical activity and weaker in those who watched TV more than two hours daily.

In conclusion, physical activity has an association with muscular fitness whereas association with TV viewing is negative independently of the level of physical activity. Single measurement of trunk muscle strength, and cross-sectional area or fat content of lumbar extensor muscles has little significance in the evaluation of the severity of low back symptoms in young adults.

Keywords: low back pain, postural balance, trunk muscles
Tiivistelmä


Tämän tutkimuksen tavoitteena oli 1) arvioida inklinometrisen tasapainomittauksen ja isometrien lihasvoimamittausten luotettavuutta, 2) arvioida alaselkäkivin yhteyttä vartalon lihasvoimaan, seisomatasapainoon sekä ojentajalihasten rasvoittumiseen ja poikkipinta-alaan ja 3) arvioida lihasvoiman yhteyttä liikunta-aktivisuuteen ja television katseluun.


Asiasanat: alaselkäkipi, seisomatasapaino, vartalon lihasvoima
To Helena
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### Abbreviations

<table>
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<th>Abbreviation</th>
<th>Definition</th>
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<tr>
<td>BMI</td>
<td>Body mass index</td>
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<tr>
<td>CI</td>
<td>Confidence interval</td>
</tr>
<tr>
<td>CLBP</td>
<td>Chronic low back pain</td>
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<tr>
<td>CSA</td>
<td>Cross-sectional area</td>
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<tr>
<td>CT</td>
<td>Computed tomography</td>
</tr>
<tr>
<td>ICC</td>
<td>Intra-class correlation coefficient</td>
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<tr>
<td>LBP</td>
<td>Low back pain</td>
</tr>
<tr>
<td>LCA</td>
<td>Latent class analysis</td>
</tr>
<tr>
<td>LOA</td>
<td>Limits of agreement</td>
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<tr>
<td>MRI</td>
<td>Magnetic resonance imaging</td>
</tr>
<tr>
<td>MVPA</td>
<td>Moderate to vigorous physical activity</td>
</tr>
<tr>
<td>N</td>
<td>Number of patients</td>
</tr>
<tr>
<td>PA</td>
<td>Physical activity</td>
</tr>
<tr>
<td>SPSS®</td>
<td>Statistical package for the social sciences</td>
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List of original articles

The thesis is based on the following articles, which are referred to in the text by their Roman numerals from I to IV.


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1 Introduction

Low back pain (LBP) is a significant health problem in all developed countries. It is often defined as pain, muscle tension or stiffness localized between the costal margin and inferior gluteal folds. When leg pain is affiliated with LBP the term sciatica is usually used (Frymoyer 1988). Traditionally LBP in children and adolescents has been considered rather unusual and as a possible sign of a serious organic disease. However, epidemiologic data from the past decades indicate that LBP is also common in youth; estimates of its prevalence in youth vary between 30% and 70%. (Balagué et al. 1999) This high prevalence is a cause of concern because a link has been presented between LBP in adolescence and chronic LBP (CLBP) in adulthood (Salminen et al. 1999, Hestbäck et al. 2003).

As in adults, the tissue origin of the majority of low back symptoms in youth remains unknown (Balagué et al. 1988). It has been estimated that about 90% of the LBP patients have non-specific LBP. Several studies have investigated potential risk factors of LBP. Non-modifiable risk factors of low back symptoms in youth include genetics, gender and age. Suggested modifiable risk factors, on the other hand, include poor back muscle strength, impaired motor control, participation in competitive sports, very high or low levels of physical activity and smoking (Balagué et al. 1994, Troussier et al. 1994, Salminen 1995). Psychosocial factors such as depression and distress have been reported to be associated with LBP as well (Härmä et al. 2002, Diepenmaat et al. 2006). However, evidence of modifiable risk factors is limited and inconsistent. In order to decrease the occurrence of LBP in adulthood, potential risk factors in adolescence should be recognized. Many studies exist on the role of physical performance in relation to future LBP, but according to a recent systematic review the significance of muscle performance or postural control in low back symptoms is still unclear (Hamberg-van Reenen et al. 2008). According to experimental studies, prolonged LBP and CLBP cause secondary changes in paraspinal muscles (Hodges 2006), and a decrease in cross-sectional area (CSA) and increased fat content of the paraspinal muscles in patients with prolonged LBP have been reported in adults (Kader et al. 2000, Lee et al. 2008). However, the association is not clear in youth (Kjaer et al. 2007).

The main objective of this study was to investigate the role of low back symptoms on trunk muscle strength, body balance and morphology of paraspinal extensor muscles among young Finnish adults. Furthermore, we wanted to
estimate the association of the level of physical activity and inactivity with trunk muscle strength.

The hypothesis of this study was that prolonged disabling low back symptoms would be associated with weaker trunk muscles and poorer postural control among young adults. Furthermore, we expected that low back symptoms would be related to decreased CSA and increased fat content of the lumbar paraspinal extensor muscles. Finally, we hypothesized that increased physical activity would be associated with increased strength of the lumbar muscles, whereas sedentary activities would be related to impaired physical capacity.
2 Review of the literature

2.1 Low back pain in young adults

In youth, LPB has historically been regarded as a rare and serious condition which could have an organic, infectious, inflammatory or neoplastic origin. However, during the past decades several studies in Finland and abroad have revealed a high prevalence of LBP also in youth (Salminen 1984, Balagué et al. 1988, Salminen et al. 1992, Andersen et al. 2006, Auvinen et al. 2008, Yao et al. 2011), very close to that reported in adults (Balagué et al. 1999).

2.1.1 Causes, consequences and classification of LBP

LPB is considered to be pain that affects the area between the lower rib cage and gluteal folds but often radiates to thighs (Frymoyer 1988). In spine research, definitions of LBP vary a lot between studies and a standard definition of LBP for epidemiological studies has therefore been proposed: pain in the low back area which should limit the usual activities or daily routines of the patient (Dionne et al. 2008). Optimally, the duration and severity of the pain and possible radiation to legs should also be estimated (Dionne et al. 2008).

Only a minority of patients can be given a precise pathoanatomical diagnosis for LBP while the majority (c. 90%) of LBP is called non-specific (Nachemson 1985, Koes et al. 2006). Serious specific causes of LBP such as fractures, tumours and anomalies represent only around 1% of all LBP cases. About 5% of all LBP patients consist of patients with radicular pain due to nerve root irritation. These patients may have sensory or motor changes in the lower extremities due to the irritation. Irritation may be caused by infection, inflammatory back pain or intervertebral disc herniations (Koes et al. 2006, Dionne et al. 2008).

The heterogeneity of LPB patients is a challenge for research and treatment of LBP, and several studies have focused on sub-grouping LBP patients. The majority of the studies focus on a biomechanical model (Billis et al. 2007). These sub-groups consist of anomalies, disc herniations, nerve root affection, degenerative changes or spinal stenosis (Billis et al. 2007). Other authors have focused on treatment-based sub-grouping. These categories are based on patients’ reactions to certain functional tests rather than on anatomical findings (Donelson et al. 1997). One of the most promising grouping systems is based on the...
biopsychosocial model introduced by Peter O’Sullivan, whose model is introduced in Fig. 1. In this classification non-specific LBP is divided into three groups of similar size. The first group consists of patients whose pain is related to psychosocial (non-organic) factors such as anxiety, depression and unresolved emotional issues (O’Sullivan 2005). The importance of these factors, especially in persistent LBP, has also been noted in a recent review (Chou & Shekelle 2010). The second subgroup consists of patients with movement impairments. These patients suffer from painful loss of normal movement of the spine due to abnormally tight lumbopelvic muscles, which leads to high compressive loading across the articulations, movement restrictions and rigidity (O’Sullivan 2005). According to O’Sullivan, the most common subgroup in clinical practice consists of patients with control impairment. These disorders are associated with deficits in the control of the symptomatic segments of the spine. Typically patients suffer from LBP in sustained postures but movement is not restricted (O’Sullivan 2005). The patients also have decreased tactile acuity and ability to control lumbar movements (Luomajoki et al. 2008, Luomajoki & Moseley 2010). Movement impairment and movement control impairment are discussed later in detail.

As classification of LBP for purposes such as intervention studies is difficult, several studies have been conducted to identify outcome measures that could help to estimate the consequences of LBP. These consequences include, in addition to presence and bothersomeness of LBP, functional status, overall well-being, and work disability (Kopec 2000, Cieza et al. 2004, Longo et al. 2010). Several rating scales have been generated in order to assess the disability due to LBP (Fairbank et al. 1980, Deyo et al. 1998). Scoring is usually based on questionnaires focusing on limitations of daily living and physical function caused by LBP. These questionnaires typically include questions concerning limitations in working, walking, bending over, sitting, lying down, dressing, sleeping and self-care (Deyo et al. 1998, Kopec 2000). As an advantage of self-report questionnaires of pain and functional status they allow clinicians to evaluate patients before and after a given treatment, and they can be used to detect short- or long-term clinical changes in symptoms and disabilities. In research they provide more accurate data of the severity of LBP compared to just asking about the presence of possible LPB. However, lack of a universally agreed conceptual model of functioning and disability has led to large variety of outcome measures (Stier-Jarmer et al. 2009). This problem could be solved with international consensus processes such as International Classification Of Functioning, Disability and Health (ICF), which has been reported to be a promising framework to assess impact of LBP (Cieza et
Although many scoring systems have been used to evaluate back function, we are still far from a single outcome evaluation system that is reliable, valid and sensitive to clinically relevant changes, taking into account both patients’ and physicians’ perspective, and is short and practical to use (Longo et al. 2010).

Classification of LBP

- Specific LBP (5-10%)
- Non-specific LBP (90-95%)

Specific medical conditions:
- Fractures
- Tumours
- Anomalies
- Nerve root affections
- Spinal canal stenosis

Central maladaptive pain (30%)
- Yellow flags
- Psychosocial factors
- Fear avoidance
- Catastrophization

Movement impairment (30%)
- Directional
- Hypomobility and pain

Movement control impairment (30%)
- Directional or multidirectional

Fig. 1. Classification of Low Back Pain according to O’Sullivan (2005).

2.1.2 Prevalence of LBP

Prevalence is the proportion of people who have the disease, in this case LBP, at a specified point in time (point prevalence) or over a specified period of time, for example one year or lifetime prevalence. Estimates of LBP prevalence vary widely between studies depending on the age of the study subjects and definition of LBP. Cumulative prevalence of LBP in youth varies from 11 to 71% (Balague et al. 1988, Olsen et al. 1992, Troussier et al. 1994, Burton et al. 1996, Harreby et al. 1999). The one-year prevalence of LBP with limitation of activities has been reported to be around 20% in 14-year-old Finnish children (Salminen et al. 1992, Taimela et al. 1997).
The prevalence of LPB increases with age. In a 5-year follow-up survey of British adolescents, the cumulative prevalence of LBP at the age of 11 was 11.6%, increasing to 50.4% (Burton et al. 1996). A cross-sectional study with more than 10,000 Finnish adolescents aged 12–18 found that the prevalence of LBP at 18 years was about 2–3 times higher than four years earlier (Vikat et al. 2000). Similar results were found in a cross-sectional Danish study of 29,424 individuals aged 12–41 (Leboeuf-Yde & Kvik 1998). The authors observed that the prevalence of LBP increased greatly in teen years, earlier in girls than in boys, and by 18 years in girls and 20 years in boys more than 50% had experienced at least one LBP episode (Leboeuf-Yde & Kvik 1998). Similarly, a recent study with 2083 Chinese schoolchildren reported increased prevalence among older subjects. The prevalences of LBP at 10–14 and 15–18 years were 21.5% and 38.2%, respectively (Yao et al. 2011). Ultimately, 70–80% of general population will suffer from LBP at some point in their lives (Frymoyer et al. 1983, Biering-Sorensen 1983, Heliövaara et al. 1989).

### 2.1.3 Risk factors of LBP

Risk factor is a factor that increases the probability of the outcome (LPB) coming true in a study population. Non-modifiable risk factors cannot be eliminated to decrease the probability of the outcome coming true. Gender is a widely studied non-modifiable risk factor for LBP. Summary of the most studied risk factors is presented in table 1.

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Reported association</th>
<th>Strength of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Female gender is associated with higher prevalence of LBP</td>
<td>Significant</td>
</tr>
<tr>
<td>Height</td>
<td>Greater total height, sitting height or fast growing spurt has been linked to LBP</td>
<td>Controversial</td>
</tr>
<tr>
<td>Weight</td>
<td>Greater weight or BMI is associated with LBP</td>
<td>Controversial</td>
</tr>
<tr>
<td>High levels of physical activity</td>
<td>High levels of physical activity or competitive sports increase risk of LBP</td>
<td>Controversial</td>
</tr>
<tr>
<td>Low levels of physical activity</td>
<td>Low levels of physical activity increase risk of LBP</td>
<td>Controversial</td>
</tr>
<tr>
<td>Sedentary activities</td>
<td>High amounts of sitting or TV-viewing are associated with LBP</td>
<td>Controversial</td>
</tr>
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</table>
Most of the previous epidemiological studies have reported a higher prevalence of LBP in girls than in boys (Salminen et al. 1992, Balagué et al. 1988, Troussier et al. 1994, Yao et al. 2011). On the contrary, a longitudinal study reported higher prevalence of LBP in boys than in girls (Burton et al. 1996). The higher prevalence in girls has been suggested to be due to hormonal differences and the occurrence of menstruation-related pains in girls, which have not been separated from musculoskeletal pains in all previous studies.

A cross-sectional study reported an association between increased sitting height and higher prevalence of LPB (Fairbank et al. 1984). Furthermore, in a follow-up study rapid growth spurt during follow-up was associated with higher prevalence of LPB (Feldman et al. 2001). Two longitudinal Finnish studies (Salminen et al. 1992b, Nissinen et al. 1994) found a positive association between height and LBP in boys, but not in girls. In contrast, another longitudinal Finnish study reported that child’s height at the baseline did not predict future LBP (Kujala et al. 1997).

The manifestation of low back pain is also influenced by genetic factors. Estimations for heritability range from 30 to 45% (Battie et al. 2007). While complex interactions are likely, genes involved in immune system, pain perception, signalling and psychological processing have been suggested to contribute to the experience of pain (Tegeder & Lötsch 2009).

Modifiable risk factors may be assumed to be more relevant as they can be modified and their normalization should reduce the burden of LBP. Such interventions are unfortunately not available. In the following, known modifiable risk factors related to physical activity or muscular fitness are reviewed in detail.

A number of studies have examined the possible association between weight or body mass index (BMI) and LBP. A Finnish study found that baseline weight was not associated with the incidence of LPB over the subsequent 12 months (Nissinen et al. 1994). Similarly, a Finnish three-year follow-up study reported that while weight at follow-up was greater in those with recurrent or continuous LBP, baseline weight was not predictive of future LPB (Salminen et al. 1995).
Overall, there is little evidence to suggest that height, growth, weight or BMI are associated with the onset of LPB symptoms (Jones & Macfarlane 2005).

The role of physical activity and inactivity in LBP have been evaluated in several studies. A U-shaped association between the level of physical activity and risk of LBP has been suggested in adults (Campello et al. 1996) and in adolescents (Jones & Macfarlane, 2005). High level of physical activity has been suggested to be a risk factor for LBP in children and adolescents (Troussier et al. 1994, Newcomer & Sinaki 1996, Kujala et al. 1999a, Taimela et al. 1997). A study of 7,048 13- to 15-year-old adolescents from Mallorca found an association between practicing any physical activity more than twice a week and increased risk of LBP (Kovacs et al. 2003). A similar association was found among 11- to 14-year-old English schoolchildren participating in physical activity more than 4 hours per week (Watson et al. 2003). A follow-up study of the same population (N=1,046) reported that those participating in sports on a frequent basis at baseline were at risk of developing LBP during the follow-up (Jones et al. 2003).

A recent study with 15- to 16-year-old adolescents (N=5,999) from the same cohort as the current thesis concluded that high participation in physical activities was associated with an increased risk of LBP (Auvinen et al. 2008). Some previous studies have shown contrasting results (Diepenmaat et al. 2006, Salminen et al. 1984, Feldman et al. 2001). The majority of these studies have used self-report questionnaires to estimate the level of physical activity. An accelerometer as an objective measure of physical activity was used in a recent prospective Danish study with 481 adolescents followed from 14 to 16 years. The authors found no obvious association between physical activity and back pain (Wedderkopp et al. 2003). In contrast to this result, the same authors found in their three-year follow-up study using the same accelerometer that high levels of physical activity seem to protect against future LBP in adolescence (Wedderkopp et al. 2009).

Some studies have suggested that the time spent on sedentary activities, e.g. watching television or playing video games, is a risk factor for LBP. A positive association between LBP and daily time spent watching television has been found in prospective epidemiological studies among children and adolescents (Balagué et al. 1988, Balagué et al. 1994, Troussier et al. 1994). However, contrary results have also been presented. A recent study from the same cohort as the current thesis reported that high amount of sitting was related to higher risk of LBP in girls but not in boys (Auvinen et al. 2008). Furthermore, among 13- to 15-year-old Spanish adolescents (N=7,048), no association was found between hours of
leisure time sitting and LBP (Kovacs et al. 2003). Similarly, in two English studies time spent on watching television or playing computer games was not associated with LBP among 1,446 11- to 14-year-old schoolchildren in cross-sectional or longitudinal settings (Jones et al. 2003, Watson et al. 2003).

Smoking has been reported to be a risk factor for LBP in numerous studies. A Finnish study with a representative sample of 11,276 adolescents reported that daily smoking was an independent risk factor for LBP (Vikat et al. 2000). Similarly, follow-up studies (Feldman et al. 2001), prospective cohort studies (Mikkonen et al. 2008) and a recent meta-analysis (Shiri et al. 2010) have reported this association.

2.1.4 Prevention of LBP

According to a recent recommendation focusing on prevention of LBP, the general nature and course of commonly experienced LBP means that there is limited scope for its primary prevention (i.e. preventing first-time onset LBP). Furthermore, the primary causative mechanism often remains unclear, which makes modification of the possible risk factors difficult (Burton et al. 2006). In addition, different intervention strategies and outcomes may be appropriate for different target populations (general population, workers, children), although overlap does exist. Overall, there is only limited evidence on primary prevention of LBP, although prevention of various consequences or recurrence of LBP (secondary prevention) is suggested to be feasible (Burton et al. 2006, Choi et al. 2010).

Physical exercise is recommended for prevention of sick leave due to LBP and the occurrence or long duration of further episodes. However, there is insufficient evidence to recommend for or against any specific type or intensity of exercise. Information and education about back problems, based on biopsychosocial principles, such as presented by O’Sullivan should be considered, but information and education focused principally on a biomedical or biomechanical model cannot be recommended (Burton et al. 2006). At the moment there is moderate quality evidence that post-treatment exercise programmes can prevent recurrences of back pain. It might be beneficial to have additional exercise programmes after formal treatment for back pain has been completed. However, the content of such a programme is difficult to specify; probably any general exercise such as stretching, strengthening, endurance training and posture education could be adequate (Choi et al. 2010). Numerous
other methods to prevent recurrence of LPB have also been studied. These include lumbar support belts, in-shoe orthoses and manipulative treatment of the spine. None of these are recommended (Burton et al. 2006).

2.2 Lumbar spine and LBP

The basic biomechanical functions of the spinal system are 1) to allow movements between body parts, 2) to carry loads and 3) to protect spinal cord and nerve roots (Panjabi 1992). Mechanical stability of the spine is necessary to enable these functions and therefore of fundamental significance to the human body.

The stabilizing system is conceptualized as consisting of three subsystems (Fig. 2.) The passive subsystem includes vertebrae, intervertebral discs, facet joint articulations, spinal ligaments and joint capsules. The active subsystem consists of muscles and tendons surrounding spinal column. The neural system consists of various force and motion transducers located in muscles, tendons and ligaments.

It also includes neural control centres (Panjabi 1992). Under normal conditions these subsystems work in harmony and provide the needed mechanical stability. The various components of the spinal column generate information about status of the spine, such as position, load and motion of each vertebra. The neural control system computes the needed stability and generates the needed muscle activation patterns (Panjabi 2003).
2.2.1 Basic anatomy of the lumbar spine

The lumbar spine consists of five vertebrae (L1-L5) as presented in Fig. 3. The main landmarks are the vertebral body, inferior and superior articular processes, spinous process and transverse process. The vertebral body carries the greatest load and is firmly connected to the adjacent body with the intervertebral disc. The articular processes make up the zygapophyseal (also called facet) joints (Platzer et al. 1992). The joint surfaces are sagittally oriented enabling good flexion and extension mobility in the lumbar spine, whereas rotation and lateral flexion are to a lesser extent possible in the lumbar spine (Pope 1989, Platzer et al. 1992). The main purpose of the transverse and spinous processes is their role as insertions for ligaments and muscles.

Intervertebral discs, apophyseal joints, the ligaments and the muscles are important structures as possible pain sources. As a principle of nociception, all structures that are innervated can also cause pain. The intervertebral disc consists of three basic components: a central nucleus pulposus which is surrounded by
anulus fibrosus, the third component being the vertebral end-plate, which covers the cranial and caudal ends of the disc with layers of cartilage. The discs form primary articulation between vertebral bodies. They also have a major role in weight bearing. The function of loadbearing in shear, compression and torsion is shared between the discs and the facet joints (Pope 1989).

Superficial abdominal muscles are divided into two groups: a) lateral group, which consists of three muscles: external abdominal oblique muscles, which arise from outer surfaces of the lowest ribs and run to the iliac crest and aponeurosis. The internal abdominal oblique muscle originates from the iliac crest and inserts at the lowest ribs and aponeurosis. The transversus abdominis muscle arises from cartilage of the ribs, thoracolumbar fascia and iliac crest and inserts to the aponeurosis. b) The medial group consists of two muscles: rectus abdominis and pyramidalis. The rectus abdominis muscle arises from cartilages of the ribs and inserts to the pubic crest. Pyramidalis arises from the pubis and radiates into the linea alba (Platzer et al. 1992).

Lumbar back muscles comprise three groups: a) Psoas major, which is subdivided into a superficial and deep part. The superficial part arises from the lowest thoracic and highest lumbar vertebral bodies and the deep part arises from the costal processes of the lumbar vertebrae. The muscle inserts to the femur. b) Quadratus lumborum and lateral transversarii, which cover the transverse processes anteriorly. c) Interspinales and intertransversarii mediales, which are short intersegmental muscles, multifidi and erector spinae (longissimus thoracis and iliocostalis lumborum). Together multifidi and erector spinae form the group of paraspinal muscles.

The multifidus muscle is the most medial of the paraspinal muscles, running in the groove formed by the spinosus processes and laminae of the vertebrae. In the lumbar area the muscle is formed by five separate bands, each of which arises from its particular lumbar spinous process L1 to L5 (Fig. 3a & 3b). Each band L1 to L5 consists of several fascicles; from five at L1 to one at L5. The shortest fascicle in each band is attached to the mamillary process of the vertebra located two segmental levels lower. The longer and more superficial fascicles insert sequentially onto mamillary processes or the dorsal surface of the sacrum three or more segmental levels lower (Fig. 3a & 3b). Thus each band forms a fanlike group of fascicles. The band arising from the L1 vertebra lies most laterally and superficially, while bands with lower origins (L2-L5) lie deep and medially. The lower bands also consist of fewer fascicles, the L5 band comprising only one fascicle, inserting onto the sacrum (Kalimo et al. 1989).
The longissimus and iliocostalis form together the erector spinae muscle group. They are situated laterally to the multifidus and are covered by the thoracolumbar fascia. The longissimus muscle forms the medial division of the erector spinae; its fibres arise from the lumbar and inferior thoracic transverse processes and attach caudally in the iliac crest. The iliocostalis muscle forms the lateral division of the erector spinae. It arises from the angles of the lower ribs and from the lateral quarter of lumbar transverse processes. (Kalimo et al. 1989, Platzer et al. 1992, Hansen et al. 2006) Cross-sectional gross anatomy of the lumbar muscles is presented in Fig. 4.
The majority of the cross-sectional area of the lumbar muscles consists of muscle fibres. The generally accepted histochemical classification divides muscle fibres into two main types, 1 and 2. Type 2 fibres are divided into subtypes 2A, 2B and 2C (Dubowitz 1985). The two main types of muscle fibre differ in their physiological properties. Type 1 fibres rely mainly on the oxidative metabolism of fats for their energy and have a very rich blood supply, which makes them very resistant to fatigue, but they twitch slowly. Type 1 fibres play an important role in the maintenance of posture. For example multifidus muscle has more type 1 fibres than type 2 fibres (Kalimo et al. 1989, Rantanen et al. 1994). All type 2 fibres are fast twitching. The subtypes of type 2 fibres differ in the amounts of glycolytic and oxidative enzymes. Type 2A fibres have some resistance to fatigue while type 2B fibres are sensitive to fatigue. Type 2C represents fibre capable of differentiation into type 2A or 2B (Dubowitz 1985). About one fourth of the CSA of the muscle consists of non-muscular tissue such as fat, fibrous connective tissue, nerves and blood vessels (Rantanen et al. 1994).
2.2.2 Role of the lumbar muscles

Function of the trunk muscles

The superficial abdominal muscles with their aponeuroses form the basis of the anterior and lateral abdominal wall. Together with the deep muscles, quadratus lumborum and psoas major are necessary for the movement of the trunk (Platzer et al. 1992). The principal motions of the spine are extension, flexion, lateral flexion and rotation (Hansen et al. 2006). Trunk flexion is mainly produced by the rectus abdominis muscle and is assisted by the external and internal oblique muscles. Trunk extension is produced by bilateral contraction of the iliocostalis lumborum and longissimus thoracis. Also psoas major, which is primary flexor of the hip, bends the trunk forward (Jorgensen et al. 2001). Lateral flexion is achieved by contraction of the external and internal oblique muscle of the abdomen. This is assisted by unilateral contraction of the iliocostalis lumborum and longissimus thoracis. Axial rotation is mainly caused by contraction of the ipsilateral internal oblique abdominal muscle and contralateral external oblique abdominal muscle. This is assisted by unilateral contraction of the iliocostalis lumborum with contributions by the lumbar segments of the longissimus and multifidus.

Trunk muscles have also a major role in lumbar stability. The contribution of bones and ligaments to lumbar stability is rather small (Crisco et al. 1992, Panjabi 1992) and the lumbar spine is unstable in the absence of muscular activity. The transversus abdominis muscle is considered to be one of the most important muscles controlling the lumbar spine. The muscle is the first to activate in response to sudden loading of the trunk; it increases intra-abdominal pressure, which stabilizes the spine. (Hodges 1999, Pietrek et al. 2000) The main function of the multifidus is to produce posterior sagittal rotation of the lumbar vertebrae and stabilize the lumbar spine. Experiments have shown the multifidus to be an important stabilizer of the lumbar spine (Wilke et al. 1995). Furthermore, long multisegmental lumbar muscles have been reported to be more efficient stabilizers of the lumbar spine (Crisco and Panjabi 1991). Generally, for most tasks of daily living very modest levels of abdominal wall co-contraction are sufficient. Depending on the task, co-contraction with the extensors and abdominals ensures stability (McGill et al. 2003). In conclusion, as the relative contributions of each muscle change throughout tasks, a single muscle cannot be identified as the most important one for the stability of the lumbar spine. Rather,
spine stability depends on the relative activation of all trunk muscles and other loading variables (Cholewicki et al. 2002, McGill et al. 2003). The importance of the muscles in stabilizing the spinal column is quite obvious when a cross-section of the body is viewed (Fig. 4.) Not only is the area of the muscles much bigger than the area of the spinal column, but the muscles have significantly larger lever arms than intervertebral discs and ligaments (Panjabi 2003).

As presented before, motor control of the spine relies on proprioceptive feedback from a variety of mechanoreceptors and other sensory organs. Impaired postural control, possibly due to injury, could lead to spine instability, especially under sudden loading conditions (McGill et al. 2003).

Trunk muscle strength and LBP

The results of several previous studies concerning the association between muscle endurance, maximal isometric or isokinetic strength and LBP are conflicting. A recent cross-sectional study reported that good isometric muscle endurance was associated with low risk of back pain in a large sample of 9,413 Danish adolescents (Andersen et al. 2006). A Finnish study with 340 children aged 11–17 years found a similar correlation (Salminen 1984). In a smaller population of 15-year-old schoolchildren an association between LPB and decreased trunk muscle endurance was found (Salminen et al. 1992b).

A one-year follow-up study with a sample of 928 Danish adults suggested that poorer trunk muscle endurance predicts LBP (Biering-Sorensen 1984). A similar association between one-year prevalence of LPB and trunk muscle endurance was found in a longitudinal study with 126 Finnish adults (Luoto et al. 1995). However, opposite results have been presented as well. A cross-sectional study with 138 Finnish adolescents aged 10–13 years did not find any association between LPB and abdominal or back muscle endurance (Kujala et al. 1992). This is in accordance with a longitudinal Finnish study of 307 asymptomatic adult workers and 123 workers with previous episodes of low back pain which found that low trunk extension endurance did not predict future LBP (Takala & Viikari-Juntura 2000).

Good isokinetic trunk muscle strength has been suggested to protect from LBP in both cross-sectional (Jones et al. 2005) and prospective (Bayramoglu et al. 2001) studies. A Finnish study with 535 adults with a 15-year follow-up reported that good dynamic trunk extension strength may protect against back-related work disability (Rissanen et al. 2002). Another study found that low
maximal isokinetic trunk extension strength predicted future LBP in subjects with previous back problems, but not in healthy subjects (Takala & Viikari-Juntura 2000). In a younger Swiss population of 117 children aged 10–16 years, the authors did not find any correlation between dynamic trunk muscle strength and LBP (Balagué et al. 1993). According to a prospective study with 96 Northern American adolescents aged 10–19 years, better maximal isometric strength of the back flexors predicted LBP (Newcomer and Sinaki 1996). A longitudinal study conducted with 215 adult males with a mean age of 32 years found a significant difference only in baseline isometric trunk rotation strength between healthy subjects and subjects with incident LBP (Masset et al. 1998). A recent systematic review concluded that there is no relationship between trunk muscle endurance and risk of LBP in adults. The review also found inconclusive evidence for a relationship between trunk muscle strength and risk of LBP (Hamberg-van Reenen et al. 2008).

The ratio of trunk extensor and flexor muscle has been suggested to be a more useful measure than extensor or flexor strength alone. A cross-sectional study conducted with 286 adults suffering from chronic LBP reported that extensor strength was affected more than flexor strength (Mayer et al. 1985). In a longitudinal study with 67 Japanese subjects aged 13–26 years without previous LBP, lower extensor-flexor ratio was observed among subjects suffering from LBP during the five-year follow-up period (Lee et al. 1999). A similar result was found in a longitudinal study with 96 adolescents (Newcomer & Sinaki 1996). Furthermore, a Finnish follow-up study reported that lower ratio was associated with an increased risk for medical consultation and sick leaves because of LBP in an adult population (Takala & Viikari-Juntura 2000). In contrast to these studies, a recent study with a 2-year follow-up did not find any association between extensor-flexor ratio and risk of LBP among Swiss adolescents (Balagué et al. 2010).

**Effects of physical activity and inactivity on trunk muscles**

Current recommendations suggest that school-aged youth should participate in moderate to vigorous physical activity (PA) 60 minutes or more each day (Strong et al. 2005). However, sitting has become more and more prevalent as many young people spend prolonged periods in front of TV and computer screens, and is one reason why the recommended level of daily physical activity is not met (Tammelin et al. 2007). Numerous studies have reported of beneficial effects of
physical activity on general health and even on mortality (Pedersen 2007). There is consistent evidence that PA in youth is positively associated with activity in adulthood, while sedentary activities and poor physical activity in adolescence are associated with poor adult health outcomes (Hallal et al. 2006). A Finnish study with 1,120 adolescent boys and 1,146 girls found a significant association between physical activity and trunk flexor endurance (Fogelholm et al. 2007). A study concluded in Gran Canaria with 114 boys with a mean age of 9.1 years reported that boys who participated in sport activities at least three hours per week had better leg muscle strength than inactive boys (Ara et al. 2004). A longitudinal Finnish study that compared 49 female adolescent athletes and 17 non-athletes reported that athlete girls had superior trunk flexion and extension forces compared to controls. Athletes also showed a larger cross-sectional area of the psoas and erector spinae muscles (Peltonen et al. 1998).

Numerous studies have focused on the association between physical activity and overweight. A longitudinal study with 871 children reported that increased sedentary activity time and hours of television viewing were associated with a greater amount of body fat (Blair et al. 2006). A similar result was found in a cross-sectional study conducted with 2,203 boys and 2,143 girls aged 12–15 years. The study reported a strong inverse association between physical fitness and overweight in adolescence (Bovet et al. 2007). A meta-analysis based on 52 studies found a significant relationship between TV viewing and obesity among children and youth. Furthermore, there was a negative association between TV viewing and physical activity (Marshall et al. 2004).

Although a positive association between physical activity and muscular strength is evident, there are no studies exploring the association between sedentary behaviour and muscular fitness in young adults.

### 2.2.3 Postural control and LBP

Under terrestrial conditions, the main task of postural control is to counteract the effects of gravity. The antigravity activity constitutes most of the output of the motor system while standing. It is achieved by activating one’s muscles to produce joint torques that compensate for the destabilizing effects of the gravitational forces on the body segments (Mergner & Rosemeier 1998). Balance is a measure of whole body performance, which requires, in addition to motor output, three interacting sensory systems: the vestibular, visual and somatosensory system. To maintain balance, a central processing system is also
needed. The brain stem pathway coordinates vestibular and visual input using proprioception from joint receptors. Cognitive programming is based on repeated and stored central commands, which lead to voluntary adjustments (Horak et al. 1989, Mergner & Rosemeier 1998, Radebold et al. 2001). Sensory information influences motor output in numerous ways at all levels of the motor system. Sensory input to the spinal cord directly triggers reflex responses. It is also essential for determining the parameters of voluntary responses. Finally, sensory input is integral for both feedback and feed-forward mechanisms. This is fundamental for maintaining postural stability during standing and walking (Holm et al. 2002).

The majority of previous studies have used body sway to represent postural balance. Body sway is a kinematic term that refers to movements of the centre of mass of the body (Gatev et al. 1999). Various methods such as cameras, force platforms and accelerometers have been used to measure body sway as a measure of postural balance in quiet standing (Gatev et al. 1999, Liston & Brouwer 1996, Kamen et al. 1998). When standing quietly, humans naturally sway at a low frequency between 0.27 and 0.45 Hz (Carpenter et al. 2001) and angular movement takes place mainly in ankle and hip joints (Gatev et al. 1999). Together, the position of the body’s centre of mass undergoes a horizontal displacement between 4 and 18 mm (Gatev et al. 1999).

Association between impaired postural balance and LBP has been widely studied. Increased body sway among adult LBP patients has been reported in some previous studies (Nies & Sinnot 1991, Hamaoui & Bouisset 2004). A Finnish follow-up study with 99 patients suffering from LBP and 61 healthy controls observed impaired postural control among female patients with severe LBP and impaired postural control among LBP patients in both genders (Luoto et al. 1998). Accordingly, a study with eight chronic LBP patients and eight controls reported that postural sway of the patients was increased, especially when subjects had to perform tasks eyes closed (Mientjes & Frank 1999). According to a study with 23 lumbar discectomy patients, subjects with LBP had increased postural sway in standing with eyes open compared with 72 healthy controls or 15 discectomy patients without LBP. When eyes were closed, both discectomy groups had worse balance than the control group (Bouche et al. 2006). In another Finnish study, LBP patients with disc herniation were reported to have impaired postural control compared to healthy controls, the difference remaining even after surgery (Leinonen et al. 2003). However, the same study group did not find
impaired postural control among 26 lumbar stenosis patients (Leinonen et al. 2002).

A study with 26 adult LBP patients and 24 controls reported that LBP patients had delayed and reduced responses to postural perturbations (Henry et al. 2006). It seems that LPB patients have impaired postural control and develop a visual compensation mechanism for underlying sensory-motor defects (Mientjes & Frank 1999, Bouche et al. 2006). As studies vary a lot with respect to study settings and methods to measure balance, there is no clear evidence that LPB is connected to impaired balance. Most of the previous studies have been conducted with adults and with rather small study populations, while the association between body sway and LBP in adolescents or young adults has not been studied.

2.3 Effects of low back pain

2.3.1 Effects of LBP on trunk muscles

Atrophy of paraspinal muscles is common in LBP. Histochemical and morphometric analyses with healthy volunteers and patients with LBP show structural changes in multifidus muscles, such as decreased cross-sectional area of type II muscle fibres and inner structure changes, such as increased core/targetoid and “moth eaten” muscle fibres (Mattila et al. 1986, Rantanen et al. 1993). Furthermore, two cardinal macroscopic signs of muscle atrophy can be found in MRI and CT: decreased size of the muscle and increased fat deposit (Kader et al. 2000, Lee et al. 2008). The mechanism for muscle atrophy has been proposed to be disuse or denervation. Disuse is not commonly regarded as the basic mechanism, as changes are usually localized and disuse should cause more generalized effects on paraspinal muscles (Hides et al. 1994). However, in an experimental study with pigs, multifidus CSA was reduced rapidly after lumbar disc or nerve root injury and atrophy could be localized to a single level (Hodges et al. 2006). Changes following disc injury could not be explained solely by denervation as distribution of the changes was different to nervation. The study suggested that changes may be due to disuse following reflex inhibitory mechanism (Hodges et al. 2006).

In numerous studies, a decreased CSA of paraspinal muscles has been reported in patients with CLBP (Parkkola et al. 1993, Danneels et al. 2000, Barker et al. 2004). On the other hand, a previous study suggests that CSA of
multifidus at single lumbar segment can change within 24 hours after acute LBP onset (Hides et al. 1994). A cross-sectional study among Finnish adults found significantly smaller CSA of the multifidus and erector spinae muscle in 48 LPB patients compared to 60 healthy volunteers (Parkkola et al. 1993). Similar results for the erector spinae muscle were obtained in an even smaller-scale Korean study (Lee et al. 2008). A retrospective study with 78 LPB patients aged 17–72 found decreased multifidus muscle CSA as a sign of atrophy in 80% of the subjects (Kader et al. 2000). A cross-sectional study with 50 English adults aged 18–65 found a significant difference between multifidus muscle CSA and duration of symptoms (Barker et al. 2004). However, a Swedish study with 112 LBP patients aged 45–55 did not found any differences in CSA of the erector spinae between patients and 36 healthy volunteers (Hultman et al. 1993). Furthermore, a cross-sectional Dutch study among adults aged 25–55 years (23 healthy volunteers and 32 patients) found a significantly smaller CSA of the multifidus in the patients only at the lowest measured level, while no significant difference in the CSA of the erector spinae or psoas muscles was observed (Danneels et al. 2000).

Fatty infiltration of paraspinal muscles has been reported to be increased in LBP patients in numerous studies. Hultman et al. found decreased radiological density of the erector spinae muscle in patients with chronic LBP (Hultman et al. 1993). Also Kader et al. found increased fat deposits of the multifidus muscle in LBP patients (Kader et al. 2000). A Swiss study with 25 adult patients with chronic LPB and 25 asymptomatic volunteers found a significantly higher fat content of the multifidus muscle in patients compared to volunteers (Mengiardi et al. 2006). Several other authors have reported a higher fat content in the back muscles among patients (Lee et al. 2008, Parkkola et al. 1993). However, a large Danish cross-sectional cohort study with 412 adults aged 40 and 442 adolescents aged 13 did find a significantly higher fat content of the lumbar multifidus in adults who had suffered from LBP at some point in their lives, but this difference was not present in adolescents (Kjaer et al. 2007). Similar findings of no significant difference in fat content of the lumbar muscles between patients and healthy volunteers were observed in the Dutch study (Danneels et al. 2000). Thus, the results of studies on the relation of LBP and the fat content of lumbar muscles are somewhat inconclusive. Furthermore, the effects of LBP on lumbar muscles have only been studied in adult populations.
2.3.2 Effects of LBP on neural control

Appropriate muscular control and movement sensation are of vital importance in preventing low back injury, because this requires an ability to anticipate events and to make suitable muscular responses. On the other hand, movement and motor control impairments are suggested to occur secondary to the presence of pain (van Dieen et al. 2003). Patients with LBP have been reported to have delayed recruitment of the transversus abdominis and deep paraspinal muscles (Hodges & Richardson 1996 Hodges & Moseley 2003). Also experimental studies report an altered recruitment of the deep trunk muscles after experimentally induced acute pain (Hodges et al. 2003). Furthermore, a cross-sectional Finnish study of 73 patients with chronic LBP reported a delayed muscle response in LBP patients (Taimela et al. 1993). The reported changes in activity of the muscles are consistent with changes in morphology presented before, which in turn could be explained by altered use of the muscle. In summary, it seems that with LBP there is alteration in the control of the spinal muscles that manifests as hypoactivity (Hodges et al. 2003b). Delayed relaxation and augmented activity of the superficial trunk muscles among patients suffering from chronic LBP have also been reported (Radebold et al. 2000).

In addition to altered muscle activation, LBP patients have deficits in lumbar proprioception (Gill & Callaghan 1998). Patients suffering from lumbar stenosis have been reported to have impairments in their sensation of lumbar movements, especially in lumbar rotation. This has been suggested to be due to peripheral sensory loss (Leinonen et al. 2002). The authors also reported impaired lumbar movement perception among 20 patients with disc herniation-related back pain. The perception was improved after discectomy, which suggests that the impairment is a reversible phenomenon (Leinonen et al. 2003). Similar altered peripheral sensation has also been observed in non-specific LBP being related to worse lumbopelvic voluntary control (Luomajoki & Moseley 2010).

It is not certain whether pain causes changes in motor control or whether motor control changes lead to pain or both. The deficits in motor control have been suggested to lead to poor control of joint movement, repeated microtrauma and pain (Panjabi 1992). The mechanism for pain to affect motor control is not clear and several possibilities have been presented. It is unlikely that one simple mechanism can mediate all the complex changes in motor control of the trunk muscles. The most likely candidates are changes in motor planning via a direct influence of pain on the motor centres, fear avoidance or changes in sensory
A recent study reports that changes in organization at motor cortex contribute to deficits in feedforward postural control (Tsao et al. 2008). The exact mechanism remains speculative. However, the authors suggest that reorganization in the motor cortical map in patients with LBP could distort the coordination between the muscles.

Pain has been suggested to lead to changes in strategy of trunk muscle control, toward increased stiffening of the spine via increased activity of the large superficial muscles (Panjabi 1992, Radebold et al. 2000, Hodges & Moseley 2003). This may have several side effects that may compromise lumbopelvic health. The argument is based on the hypothesis that contribution of the deep muscles to trunk control is fine tuning of intervertebral motion, which may be lost due to stiffening (Hodges & Moseley 2003). This is also in accordance with the LBP classification presented before (O’Sullivan 2005). As conclusion, it seems that LBP is strongly associated with deficit in motor control and that changes in this system may also lead to impaired postural control.

**Fig. 5. Possible mechanisms for pain to affect motor control (Hodges & Moseley 2003).**
3 Purpose of the study

The main objective was to analyse the role of paraspinal muscles (strength, cross-sectional area, fat content) in low back symptoms in young Finnish adults. Furthermore, we wanted to evaluate the effects of physical activity and inactivity on muscle strength.

The specific aims of the study were:

1. To analyse the reproducibility of maximal isometric trunk muscle strength and inclinometric body sway measurements and to establish reference values for these measurements.
2. To evaluate whether isometric trunk muscle strength and body sway are associated with low back symptoms.
3. To study how the level of physical activity and time spent on TV viewing are associated with trunk muscle strength.
4. To evaluate whether low back symptoms are associated with paraspinal fat content and cross sectional area.
4 Subjects and methods

4.1 Study population

The study population consisted of the Northern Finland Birth Cohort 1986 (NFBC 1986), which originally included data on 9,479 children with an expected date of birth between July 1, 1985 and June 30, 1986 in the two northernmost provinces of Finland, Oulu and Lapland (Järvelin et al. 1993). The follow-up at a mean age of 16 years, conducted between May 2001 and April 2002, included a postal questionnaire, which was sent to the members of the cohort who were alive and whose addresses were known (n=9,215). The response rate was 78% (n=7182). The questionnaire included items about health, including six-month period prevalence of LBP, lifestyle factors such as physical activity, sedentary behaviour, and smoking. Weight and height were measured.

The 17- to 18-year follow-up postal questionnaire (from now on called 18-year follow-up) was conducted between September 2003 and January 2004. It included items about lifestyle and general health addressing specifically musculoskeletal health. It was sent to a subcohort of the birth cohort living within a 100 km radius of the city of Oulu (n=2,969). Altogether 2,012 subjects responded to this survey (response rate 68%). The respondents were also invited to participate in a clinical examination.

Altogether 874 subjects (381 males and 493 females) participated in the clinical examination between June and September 2005 (44% of those who were invited). The mean age of the subjects at the time of examination was 19.1 years (SD 0.3). During the examination subjects also filled in a questionnaire similar to the postal questionnaire used at the age of 18. All subjects who participated in physical examination were invited to participate in lumbar spine MRI. A total of 554 subjects (321 females and 233 males, 63% of those who were invited) were scanned. Due to limited MRI resources Opposed-Phase images were taken from 387 randomly selected subjects (233 females and 154 males). The mean age of the subjects at the time of examination was 21.1 years. The flow chart of the study is presented in Fig. 5.

The study follows the principles of the Declaration of Helsinki. The participants took part on a voluntary basis and signed their informed consent at 16 and 18 years. Additionally, an informed consent was signed by their parents at the
age 16 years. The study was approved by the Ethics Committee of the Northern Ostrobothnia Hospital District.
Fig. 6. Study flow chart of the Oulu Back Study, adapted from Auvinen 2010.
4.2 Methods

4.2.1 Questionnaires

All the questionnaires (at the mean age of 18, 19 and 21 years) included the same items about LBP history and about the intensity, frequency and bothersomeness of LBP. The questions concerning LBP were supported by a manikin indicating the low back region as a shaded area between the lower ribs and gluteal folds (Fig. 6).

Different combinations of variables and different cut-off values for categorical and continuous variables were explored. The best model in study II was obtained with a combination of the following variables at 18 and 19 years: 1) lifetime prevalence of LBP (no vs. yes), 2) six-month prevalence of LBP (no vs. yes), 3) consultation of a physician because of LBP (no vs. yes), 4) taking pain medication because of LBP (no vs. yes), 5) restriction of daily activities because of LBP (no vs. yes), 6) restricted participation in sports because of LBP (no vs. yes), 7) intensity of LBP at least 3 on a 10-point numerical scale (no vs. yes), and 8) the existence of a (previous or current) LBP episode that had lasted for more than two weeks (no vs. at least one episode). In the study IV a combination of the same variables except lifetime prevalence of LBP was explored at 18, 19 and 21 years. The amount of moderate-to-vigorous intensity physical activity (MVPA) after school hours was evaluated by asking: "How much do you participate in brisk physical activity outside school hours?" In the questionnaire, the term 'brisk' was defined as physical activity causing at least some sweating and shortness of breath. Answering options were: 1) never, 2) about ½ hour, 3) about 1 hour, 4) 2–3 hours, 5) 4–6 hours, and 6) 7 hours or more per week. For the analysis, groups 1 to 3 were combined. In response to an open-ended question, subjects reported how many hours per day, on average, they spent watching TV. The subjects were divided into two categories according to their TV viewing per day: 1) less than 2 hours, and 2) 2 hours or more per day. This two-hour limit chosen for TV viewing was based on the recommendation of the American Academy of Pediatrics that the use of entertainment media should be restricted to two hours per day to avoid negative effects on body weight and other health outcomes (American Academy of Pediatrics 2001). The test-retest reliability of these variables has been reported to be fairly good, the intraclass correlation coefficient being 0.83 for MVPA and 0.74 for TV viewing among Finnish adolescents aged 15 to 16 years (Tammelin et al. 2007).
4.2.2 Clinical examination

The clinical examination at the age of 19 included measurements of body height, weight, postural balance and muscle strength. Height and weight were measured once. Precision of the height measurements was 0.5 cm. In the weight measurements precision was 0.1 kg. Body Mass Index (BMI) was calculated as weight in kilograms (kg) divided by the square of height in metres (m²).

Fig. 7. The anatomical areas of inquired musculoskeletal pains.
In this study body sway was used to represent postural balance of the subjects. Body sway measurements were performed under standardized conditions using an inclinometry-based method (Body Sway Measurement System, Crea Research Co. Oulu, Finland) (Korpelainen et al. 2005). The device consisted of a belt fastened firmly at the level of the iliac crest, an inflexible measuring rod, an inclinometric module, a joint structure lying on the ground, a power unit, and a PC. The deviating movement of the measuring rod was calculated separately for the side-to-side and forward-backward directions at the individually selected calculation height (h=0.55 x body height) and the recorded sway parameters were the total path length, area and speed of postural sway. The path length was obtained by calculating the distance between the sequential location points of each sample, and after that, summing the values. After that, the algorithm of the software approximated the outlines of the measured sway and calculated the assessed area. During the measurement, the subjects were instructed to remove their shoes and stand with their feet together and arms down their sides. They were told to gaze at a fixation point located on a wall 2.5 metres ahead of them. Each test lasted 60 seconds and each subject performed the tests twice with eyes open and twice with eyes closed. The better result was recorded from each test. The measuring device is presented in Fig. 7.

In the intra-rater reproducibility study, the same tester performed body sway and strength measurements under standardized conditions. The test was repeated within seven days, and the subjects were told to keep their daily routines as similar as possible and to avoid, for instance, alcohol or heavy physical exercise. The actual maintenance of the routines was controlled with a questionnaire. When assessing inter-rater reproducibility, the same subject was tested twice and another tester repeated the test within 30 minutes after the first measurement.
Trunk muscle strength

Maximal isometric trunk muscle strength was measured with a computerized strain-gauge dynamometer (NewTest Co. Oulu, Finland) in standing position (Fig. 8.). When measuring flexion and rotations, resting pads were placed against the popliteal fossa, lumbar spine and on scapular level and a padded sternal pad was positioned against the chest at the same level with the scapular pad. When measuring extension, pads were placed against the proximal part of the tibia, pelvis and sternum. Scapular pad was positioned at the height of the scapular spines. Subjects were instructed to perform maximal push against the pad for about three seconds. Each measurement was performed three times and the best performance was recorded. Results that exceeded the second best result of the same subject by more than 5 kg were excluded. In this case one new repetition
was performed. If the best value still exceeded others by more than 5 kg, the second best result was recorded. Ratios between extensor and flexor strength and between rotation strengths were calculated for all subjects.

Fig. 9. Measuring maximal isometric trunk extension (Fig. on the left) and trunk extension (Fig. on the right).

*Dynamic leg extensor strength*

The speed-strength of the leg extensor muscles was measured using a counter-movement jump test (CMJ) on a contact mat (Powertimer 1.0, Newtest Ltd., Oulu, Finland) connected to a digital timer (±0.001 s). The height of the vertical jump was calculated from the measured flight time. The performance goal for the jumps was to obtain maximum height. To optimize subjects’ jump technique, no restrictions were placed on the magnitude of the countermovement. All jumps were performed with hands placed on hips. Three jumps were performed and the best was recorded.
4.2.3 Magnetic resonance imaging

MRI scans were obtained using a 1.5-T unit (Signa, General Electric, Milwaukee, WI) with the imaging protocol of sagittal T1-weighted (440/14 [repetition time msec/echo time msec]) spin echo and T2-weighted (3960/116) fast spin echo of the entire lumbar spine using a phased array spine coil (USA Instruments, Aurora OH, USA). The number of excitations for T1-weighted images was 1 and for T2-weighted images 4. Echo train length for T2-weighted images was 29. The image matrix was 256 x 224 for T1-weighted images and 448 x 224 for T2-weighted images. Field of view was 28 x 28 cm and slice thickness 4 mm with 1 mm interslice gap. Axial dual-echo T1-weighted fast-spoiled gradient echo (FSPGR) was used to obtain in-phase and opposed-phase images (TR/TE 160/2.5 and 5.2, flip angle 90, NEX 1, FOV 18cm, matrix 256 × 160, 4 mm thick slices with 1 mm interslice gap).

Opposed Phase imaging is based on the different precessional frequencies of water and fat protons (Earls & Krinsky 1997). This frequency difference can be utilized to generate In-Phase (IP) and Opposed-Phase (OP) images in which the water net magnetization vector is either aligned with (IP) or opposed to (OP) the fat net magnetization vector. In tissues that consist of a mixture of water and fat this results in signal intensity loss on OP images relative to IP images. Only voxels containing either mostly fat or water do not have a destructive OP effect and do not lose signal intensity. Therefore, the more the (muscle) tissue contains fat, the more it loses signal intensity in OP images, assuming that the water fraction remains dominant.

CSA of erector spinae and multifidus muscles was measured from the image slice closest to the upper end plate of L4 vertebral body (Fig. 8a). CSA of the erector spinae muscles was measured from axial T2-weighted images (Fig. 8b), while the CSA of the multifidus muscle was measured from the axial T1-weighted OP-images (Fig. 8a). Outlines of the muscles were manually traced on the computer screen of a clinical workstation (neaView Radiology version 2.21, Neagen, Finland). The same region as in the OP-images was automatically copied to the IP-images (Fig. 9b). Mean signal intensities and standard deviation of the signal intensity of the OP and IP images were recorded from the same region. The relative difference (signal loss) between the IP and OP intensities was then calculated with the formula: (IP-OP)/IP*100%. Figures 9a and 9b represent a subject with a higher fat content (relative difference 33.7% in right and 31.9% in left multifidus).
Fig. 10. Muscle cross-sectional areas (CSA) were measured by tracing manually muscle boundaries over the axial images at the level of the upper end plate of the L4 vertebral body (Fig. 8a). The dotted lines indicate the muscle boundaries. CSA of the erector spinae was measured from T2-weighted images (Fig. 8b).
Fig. 11. CSA of the multifidus muscles was measured from T1-weighted Opposed-Phase (OP) images (Fig. 9a). Regions in the OP-images were automatically copied to the same anatomical locations in In-Phase (IP) images (Fig. 9b). Relative difference (signal loss) between the regions in IP and OP images was then calculated with the formula: \( \frac{(IP-OP)}{IP} \times 100\% \). There is a clear difference in signal intensities between the OP image (Fig. 9a) and IP image (Fig. 9b), the OP image showing a 33.7\% loss of signal intensity in the multifidus muscle.
### 4.2.4 Statistical methods

The chi square test was used for categorical variables to evaluate the statistical difference in the chosen variable between the groups. The unpaired t-test was used for continuous variables to analyse the statistical significance of the difference between groups, such as the difference in muscle strength values between the genders. P-values under 0.05 were considered significant. Reference values were estimated following the recommendation of The International Federation of Clinical Chemistry (IFCC) and the values were calculated using the RefVal program (Solberg 2004). The program was used to detect and eliminate outliers. Fit to the Gaussian distribution was also tested with the program.

Reproducibility of the measurements was evaluated by calculating the intra-class correlation coefficient (ICC) (Shrout & Fleiss 1979), which has been recommended for tests of reliability (Rankin & Stokes 1998). Calculations were carried out with SPSS for Windows version 14.0. Intra-rater reproducibility was calculated with a one-way random model, which uses ICC (1,1) equation. Inter-rater reproducibility was calculated using two-way mixed model, which uses ICC (3,1) equation (Shrout & Fleiss 1979). The Bland & Altman method was used to assess the agreement between two measurements (Bland & Altman 1986). In addition, 95% limits of agreement (LOA), the mean of differences (d), standard deviation of the difference (SD Diff), and standard error of the mean were calculated.

The mean values of muscular fitness tests with 95% confidence intervals (CI) were calculated for the different categories of physical activity and TV viewing. Multivariate analysis of covariance (MANCOVA) was used to analyse the differences between the categories. The results from muscular fitness tests were used as outcome variables and MVPA or TV viewing as explanatory variables. In the second phase, the results were adjusted for body weight, height and smoking. Thereafter, independent associations between musculoskeletal fitness, physical activity and TV viewing were estimated in MANCOVA. The unpaired t-test was used to evaluate the statistical significance of the differences between subgroups. The subjects who were least active (less than 2 hours MVPA per week) and those who spent the least time watching TV (less than 2 hours per day) were used as reference groups in the analyses.

Clustering of the subjects according to low back symptoms was based on the Latent Class Analysis (LCA) (Magidson & Vermunt 2004). LCA represents a special case of cluster modelling, where the latent classes explain the observed
dependent variables similar to factor analysis (Bartholomew & Knott 1999). In contrast to factor analysis, however, LCA provides a classification of individuals. The LCA analysis used in this study is recognized as a useful tool for locating homogenous subgroups (Formann & Kohlmann 1996). Subjects in the LCA groups are locally independent with respect to the observed analysis variables. Using the LCA method and Bayes’ theorem, a posteriori probability is calculated for each case in each class. Each case is then assigned to the latent class with the highest a posteriori probability. Latent class models are fitted successively, starting with a two-cluster model and then adding another cluster for each successive model. The number of clusters was determined and checked with different statistical diagnostics, which included Bayesian Information Criterion (BIC), and the Vuong-Lo-Mendell-Rubin Likelihood Ratio Test (LRT). For LCA analyses, we used the M-Plus software, version 5.

To analyse the association between low back symptom clusters, muscle strength and balance the measured variables (trunk extension, trunk flexion, trunk rotation, extension-flexion ratio, body sway) were standardized and treated as continuous variables in all analyses to provide risk estimates associated with a one SD increase in the predictor variables. Due to skewness in the distribution of all measured variables, they were logarithmically transformed. Because the outcome involved six categories, a multinomial logistic regression model was used in the analyses to investigate the relationships between the measured variables and the symptom clusters. To examine the role of gender in the associations between the measured variables and LCA, we entered gender and the corresponding interaction terms into the models. The obtained crude odds ratios were adjusted for possible confounders (height, weight, smoking, physical activity, and mean number of daily sedentary hours).

One-way ANOVA was used to compare muscle CSA and fat content of the paraspinal muscles between the LCA subgroups. P-values under 0.05 were considered significant.
5 Results

5.1 Characteristics of the study population

Anthropometry, physical activity, TV viewing and smoking habits of the study subjects are presented in Table 1. The males participating in the study were physically more active than the females: Forty-two percent of participants and 35% of non-participants (those who answered postal questionnaires but did not take part in physical examination) reported exercising at least four times a week (p=0.03). Male participants also smoked less than non-participants (p<0.001). In women, there were no significant differences in the prevalence of LBP, physical activity, or smoking between participants and non-participants. Women tended to be more active in participating in the study than men (46% of those invited vs. 42% of invited males; p=0.10).

5.2 Prevalence of low back pain and sciatica

The prevalence of LBP and sciatica at 19 years is presented in Fig. 10. The lifetime prevalence of self-reported LBP was 64% (n=532) and one-year prevalence 57% (n=474). The six-month prevalence of "Reporting LBP" was 50% (n=416) and of "Consultation for LBP" 7% (n=58). The lifetime prevalence of sciatica was 8% (n=66). There was a significant difference between genders in the prevalence of "Reporting LBP" during the past six months (53% in girls and 45% in boys; p=0.014) and in lifetime prevalence of sciatica (10% in girls and 5% in boys; p=0.003), whereas the prevalence of "Consultation for LBP" was 7% in both genders.
Table 2. Characteristics of the total study population at the age of 19.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Males</th>
<th>Females</th>
<th>Total</th>
<th>p-value b</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n=381</td>
<td>n=493</td>
<td>n=874</td>
<td></td>
</tr>
<tr>
<td>Height, cm Mean (95% CI)</td>
<td>177.9 (177.3 -178.6)</td>
<td>164.2 (163.7 - 164.7)</td>
<td>170.2 (169.6 - 170.8)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Mass, kg Mean (95% CI)</td>
<td>75.6 (74.2 - 76.9)</td>
<td>60.2 (59.3 - 61.1)</td>
<td>66.9 (66.0 - 67.8)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Moderate to vigorous physical activity a, hours per week % (n)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;2</td>
<td>28 (105)</td>
<td>41 (201)</td>
<td>35 (306)</td>
<td></td>
</tr>
<tr>
<td>2-3</td>
<td>26 (97)</td>
<td>33 (160)</td>
<td>29 (257)</td>
<td></td>
</tr>
<tr>
<td>4-6</td>
<td>27 (101)</td>
<td>20 (97)</td>
<td>23 (198)</td>
<td></td>
</tr>
<tr>
<td>≥7</td>
<td>21 (78)</td>
<td>7 (35)</td>
<td>13 (113)</td>
<td></td>
</tr>
<tr>
<td>TV viewing, hours per day % (n)</td>
<td></td>
<td></td>
<td></td>
<td>0.141</td>
</tr>
<tr>
<td>&lt;2</td>
<td>51 (193)</td>
<td>46 (225)</td>
<td>48 (418)</td>
<td></td>
</tr>
<tr>
<td>≥2</td>
<td>49 (188)</td>
<td>54 (268)</td>
<td>52 (456)</td>
<td></td>
</tr>
<tr>
<td>Smoking status % (n)</td>
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<td></td>
<td></td>
<td>0.242</td>
</tr>
<tr>
<td>non-smoker</td>
<td>59 (223)</td>
<td>57 (280)</td>
<td>58 (503)</td>
<td></td>
</tr>
<tr>
<td>non-regular smoker</td>
<td>17 (66)</td>
<td>20 (100)</td>
<td>19 (166)</td>
<td></td>
</tr>
<tr>
<td>regular smoker</td>
<td>24 (92)</td>
<td>23 (113)</td>
<td>23 (205)</td>
<td></td>
</tr>
</tbody>
</table>

a Moderate to vigorous physical activity was defined as causing at least some sweating and breathlessness.

b P-value for gender difference from the Chi-square test
5.3 Reproducibility of the measurements

5.3.1 Body sway and trunk muscle strength measurements

The intra-rater reproducibility of trunk muscle strength measurements and body sway measurements is presented in Table 2. The ICC values of the muscle strength measurements varied between 0.84 and 0.95, indicating good or excellent reliability. The mean difference (d) between the first and second measurements for all the strength variables was negative (range from -2.35 to -0.16), indicating a slight systematic improvement between measurements.

The ICC values for body sway measurements ranged from 0.39 to 0.74, indicating poor to moderate test-retest reproducibility between measurements.
The mean difference values ranged from -0.67 to 0.10, staying close to zero and indicating a slight systematic improvement between measurements.

The results of the muscle strength tests and the body sway measurements performed by two different raters are presented in Table 2. The ICC values in the repeated trunk testing varied between 0.84 and 0.88, suggesting high reproducibility. However, the results revealed quite a wide range of measurement error and poor agreement between the raters, especially in repeated trunk flexion testing (mean difference -5.62, 95% LOA -29.40–18.16). The Bland and Altman analysis of the trunk extension shows that the magnitude of the differences was not dependent on the magnitude of the measurement value (Fig. 11). The figure also indicates systematic error as almost all values are scattered above zero.

In the repeated sway path and length measurements ICC values ranged from 0.61 to 0.85, indicating acceptable reproducibility. ICC values for the sway area remained slightly under acceptable level. Mean difference (d) between the two measurements was close to zero, except in sway path length in the eyes closed test, where the value was -2.74 cm. Fig. 12 illustrates the scattering of the eyes open sway area values. The mean difference was zero, indicating no systematic bias. However, SDDiff was 0.5, indicating quite wide limits of agreement.

Table 3. Reproducibility of isometric trunk muscle strength measurements and body sway measurements in young adults.

<table>
<thead>
<tr>
<th>Variable</th>
<th>ICC (95% CI)1</th>
<th>d 2</th>
<th>SE of d 2</th>
<th>SDDiff 3</th>
<th>Aver. 95% limits of agreement5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intra-rater measurements n=19</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extension (kg)</td>
<td>0.94 (0.84 – 0.98)</td>
<td>-2.35</td>
<td>1.94</td>
<td>8.23</td>
<td>70.14 (-18.81 , 14.11)</td>
</tr>
<tr>
<td>Flexion (kg)</td>
<td>0.95 (0.88 – 0.98)</td>
<td>-0.16</td>
<td>1.75</td>
<td>7.44</td>
<td>50.47 (-15.04 , 14.72)</td>
</tr>
<tr>
<td>Rotation left (kg)</td>
<td>0.90 (0.75 – 0.96)</td>
<td>-1.98</td>
<td>0.84</td>
<td>3.65</td>
<td>18.44 (-9.28 , 5.32)</td>
</tr>
<tr>
<td>Rotation right (kg)</td>
<td>0.84 (0.65 – 0.84)</td>
<td>-0.45</td>
<td>0.91</td>
<td>3.96</td>
<td>14.73 (-8.37 , 7.47)</td>
</tr>
<tr>
<td><strong>Eyes open</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sway path length (cm)</td>
<td>0.55 (0.14 – 0.80)</td>
<td>-0.67</td>
<td>0.91</td>
<td>3.87</td>
<td>18.53 (-8.41 , 7.07)</td>
</tr>
<tr>
<td>Velocity (cm/s)</td>
<td>0.40 (0.00 – 0.72)</td>
<td>-0.02</td>
<td>0.02</td>
<td>0.09</td>
<td>0.31 (-0.20 , 0.16)</td>
</tr>
<tr>
<td>Area (cm²)</td>
<td>0.63 (0.25 – 0.84)</td>
<td>0.10</td>
<td>0.11</td>
<td>0.46</td>
<td>1.13 (-0.82 , 1.02)</td>
</tr>
<tr>
<td><strong>Eyes closed</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sway path length (cm)</td>
<td>0.74 (0.44 – 0.90)</td>
<td>-0.66</td>
<td>1.57</td>
<td>6.70</td>
<td>34.90 (-14.06 , 12.74)</td>
</tr>
<tr>
<td>Velocity (cm/s)</td>
<td>0.52 (0.10 – 0.79)</td>
<td>-0.04</td>
<td>0.04</td>
<td>0.15</td>
<td>0.59 (-0.34 , 0.26)</td>
</tr>
<tr>
<td>Area (cm²)</td>
<td>0.39 (0.06 – 0.72)</td>
<td>-0.07</td>
<td>0.26</td>
<td>1.11</td>
<td>2.21 (-2.29 , 2.15)</td>
</tr>
<tr>
<td>Variable</td>
<td>ICC (95% CI)</td>
<td>d²</td>
<td>SE of d²</td>
<td>SD_{diff}²</td>
<td>Aver. value</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>--------------</td>
<td>-----</td>
<td>----------</td>
<td>------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Inter-rater measurements n=14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extension (kg)</td>
<td>0.88 (0.67 - 0.96)</td>
<td>7.95</td>
<td>3.13</td>
<td>11.73</td>
<td>93.25</td>
</tr>
<tr>
<td>Flexion (kg)</td>
<td>0.87 (0.64 - 0.96)</td>
<td>-5.62</td>
<td>3.18</td>
<td>11.89</td>
<td>68.16</td>
</tr>
<tr>
<td>Rotation left (kg)</td>
<td>0.84 (0.58 - 0.94)</td>
<td>-0.78</td>
<td>1.17</td>
<td>4.37</td>
<td>26.13</td>
</tr>
<tr>
<td>Rotation right (kg)</td>
<td>0.84 (0.56 - 0.94)</td>
<td>-1.28</td>
<td>1.32</td>
<td>4.99</td>
<td>26.13</td>
</tr>
<tr>
<td>Eyes open</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sway path length (cm)</td>
<td>0.85 (0.59 – 0.95)</td>
<td>0.28</td>
<td>0.95</td>
<td>3.56</td>
<td>20.24</td>
</tr>
<tr>
<td>Velocity (cm/s)</td>
<td>0.81 (0.51 – 0.94)</td>
<td>0.01</td>
<td>0.02</td>
<td>0.07</td>
<td>0.34</td>
</tr>
<tr>
<td>Area (cm²)</td>
<td>0.62 (0.15 – 0.86)</td>
<td>0.00</td>
<td>0.13</td>
<td>0.50</td>
<td>1.20</td>
</tr>
<tr>
<td>Eyes closed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sway path length (cm)</td>
<td>0.79 (0.47 – 0.93)</td>
<td>-2.74</td>
<td>1.77</td>
<td>6.63</td>
<td>36.95</td>
</tr>
<tr>
<td>Velocity (cm/s)</td>
<td>0.78 (0.45 – 0.93)</td>
<td>-0.04</td>
<td>0.03</td>
<td>0.12</td>
<td>0.62</td>
</tr>
<tr>
<td>Area (cm²)</td>
<td>0.61 (0.14 – 0.86)</td>
<td>-0.31</td>
<td>0.22</td>
<td>0.83</td>
<td>2.23</td>
</tr>
</tbody>
</table>

¹ Intraclass Correlation Coefficient.
² d is mean difference. The closer the mean difference is to zero, the better the agreement.
³ SE of d is the standard error of d.
⁴ SD_{diff} is the standard deviation of the differences. The smaller the number, the better the agreement.
⁵ 95% limits of agreement (d ± 2SD_{diff}) indicate a range of error according to which clinically values would have to change by these amounts before real change can be said to have occurred.
Fig. 13. Bland and Altman analysis for inter-rater reproducibility of the maximal isometric extension measurements (n=14).

Fig. 14. Bland and Altman analysis for inter-rater reproducibility of the body sway area measurements (n=14).
5.3.2 Muscle CSA and fat content measurements

For the intra-rater repeatability analysis, the principal investigator read 35 randomly selected subjects two times one month apart in order to avoid the identification of the subjects. Intraclass Correlation Coefficient (ICC) of the CSA measurements ranged from 0.85 to 0.86 and of the signal intensity measurements from 0.86 to 0.88. For the analysis of inter-rater reliability, an experienced radiologist performed the same measurements on 35 randomly selected subjects of the same study group. Inter-rater ICC of the CSA measurements ranged from 0.83 to 0.85 and of the signal intensity measurements from 0.85 to 0.87.

5.4 Reference values of body sway and isometric trunk muscle strength

The 95% normative values and quartiles of the body sway measurements are presented in Table 3. All the sway measurement values were lower in women than in men. The average sway path length with eyes open was 17.9 cm (SD 4.8) in women and 19.3 cm (SD 7.7) in men (p=0.001). The average path length with eyes closed was 33.5 cm (SD 9.9) in women and 37.8 cm (SD 11.1) in men (p<0.001). The average velocity with eyes open was 0.30 cm/s (SD 0.09) in women and 0.32 cm/s (SD 0.09) in men (p=0.001) and with eyes closed 0.56 cm/s (SD 0.17) in women and 0.63 cm/s (SD 0.19) in men (p<0.001). The average area for body sway with eyes open was 1.07 cm² (SD 0.55) in women and 1.23 cm² (SD 0.68) in men (p<0.001). With eyes closed, the values were 2.17 cm² (SD 1.30) in women and 2.66 (SD 1.50) in men (p<0.001).

The 95% normative values and quartiles of the isometric trunk strength measurements are presented in Table 4. Men performed significantly better than women in all muscle strength tests. Back extensor muscles were generally stronger than back flexor muscles. Extension-flexion ratio was higher in women (mean 1.63, SD 0.44) than in men (mean 1.37, SD 0.33) (p<0.001).
Table 4. Normative values (95%) and quartiles for body sway in young adults (n=874).

<table>
<thead>
<tr>
<th>Body sway parameter</th>
<th>2.5%</th>
<th>25%</th>
<th>50%</th>
<th>75%</th>
<th>97.5%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Women</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eyes open</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sway path length (cm)</td>
<td>9.50</td>
<td>14.30</td>
<td>17.60</td>
<td>21.30</td>
<td>27.90</td>
</tr>
<tr>
<td>Velocity (cm/s)</td>
<td>0.20</td>
<td>0.20</td>
<td>0.30</td>
<td>0.40</td>
<td>0.50</td>
</tr>
<tr>
<td>Area (cm²)</td>
<td>0.30</td>
<td>0.70</td>
<td>1.00</td>
<td>1.30</td>
<td>2.40</td>
</tr>
<tr>
<td>Eyes closed</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Sway path length (cm)</td>
<td>17.00</td>
<td>26.10</td>
<td>32.15</td>
<td>40.00</td>
<td>54.90</td>
</tr>
<tr>
<td>Velocity (cm/s)</td>
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<td>0.40</td>
<td>0.50</td>
<td>0.70</td>
<td>0.90</td>
</tr>
<tr>
<td>Area (cm²)</td>
<td>0.60</td>
<td>1.30</td>
<td>1.90</td>
<td>2.80</td>
<td>4.90</td>
</tr>
<tr>
<td><strong>Men</strong></td>
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<td></td>
</tr>
<tr>
<td>Eyes open</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sway path length (cm)</td>
<td>10.34</td>
<td>15.45</td>
<td>18.30</td>
<td>22.05</td>
<td>30.92</td>
</tr>
<tr>
<td>Velocity (cm/s)</td>
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<td>0.30</td>
<td>0.40</td>
<td>0.50</td>
</tr>
<tr>
<td>Area (cm²)</td>
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<td>0.80</td>
<td>1.10</td>
<td>1.50</td>
<td>2.90</td>
</tr>
<tr>
<td>Eyes closed</td>
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<td></td>
</tr>
<tr>
<td>Sway path length (cm)</td>
<td>20.00</td>
<td>29.80</td>
<td>36.20</td>
<td>44.85</td>
<td>62.40</td>
</tr>
<tr>
<td>Velocity (cm/s)</td>
<td>0.30</td>
<td>0.50</td>
<td>0.60</td>
<td>0.70</td>
<td>1.10</td>
</tr>
<tr>
<td>Area (cm²)</td>
<td>0.81</td>
<td>1.70</td>
<td>2.30</td>
<td>3.30</td>
<td>6.12</td>
</tr>
</tbody>
</table>

Table 5. Normative values and quartiles for maximal isometric strength in young adults (n=874).

<table>
<thead>
<tr>
<th>Muscle strength parameter</th>
<th>2.5%</th>
<th>25%</th>
<th>50%</th>
<th>75%</th>
<th>97.5%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Women</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extension</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absolute (kg)</td>
<td>27.40</td>
<td>46.85</td>
<td>56.80</td>
<td>64.20</td>
<td>84.60</td>
</tr>
<tr>
<td>Weight-related</td>
<td>0.45</td>
<td>0.79</td>
<td>0.96</td>
<td>1.10</td>
<td>1.42</td>
</tr>
<tr>
<td>Flexion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absolute (kg)</td>
<td>15.70</td>
<td>27.20</td>
<td>35.20</td>
<td>43.40</td>
<td>67.10</td>
</tr>
<tr>
<td>Weight-related</td>
<td>0.26</td>
<td>0.47</td>
<td>0.59</td>
<td>0.73</td>
<td>1.13</td>
</tr>
<tr>
<td>Rotation left</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absolute (kg)</td>
<td>4.50</td>
<td>8.90</td>
<td>11.90</td>
<td>13.30</td>
<td>26.00</td>
</tr>
<tr>
<td>Weight-related</td>
<td>0.08</td>
<td>0.15</td>
<td>0.20</td>
<td>0.26</td>
<td>0.40</td>
</tr>
<tr>
<td>Rotation right</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absolute (kg)</td>
<td>5.30</td>
<td>10.20</td>
<td>13.30</td>
<td>17.10</td>
<td>25.70</td>
</tr>
<tr>
<td>Weight-related</td>
<td>0.09</td>
<td>0.17</td>
<td>0.22</td>
<td>0.28</td>
<td>0.39</td>
</tr>
<tr>
<td>Extensor - flexor ratio</td>
<td>0.89</td>
<td>1.34</td>
<td>1.57</td>
<td>1.88</td>
<td>2.63</td>
</tr>
<tr>
<td>Left to right rotation ratio</td>
<td>0.45</td>
<td>0.72</td>
<td>0.93</td>
<td>1.13</td>
<td>1.78</td>
</tr>
</tbody>
</table>
## 5.5 Clustering of the study subjects

As presented in the Methods section, optimal combinations of variables to form natural clusters were slightly different. This is due to slightly different study groups (n=874 in study II vs. 554 in study IV).

In study II, the optimal number of clusters was found to be six (low p-value with a levelling of AIC decrease). The clustering was first conducted for 743 individuals who had a complete data set or less than six missing values. Individuals (n=131) with missing data were then evaluated manually in order to place them into the right clusters. Cluster "6" represents the clearly asymptomatic with no LBP and cluster "1" those with severe LBP symptoms, whereas clusters "2", "3", "4", "5" lie in between. The number of subjects in each cluster and the mean scores of the symptoms are presented in Table 5.

For study IV, the clustering was performed first for the 468 individuals who had a complete data set or less than six missing values. Ninety-eight subjects had more than six missing values and were therefore evaluated manually in order to fit them into the right cluster. Finally both the questionnaire data and MRI scans were available for 554 subjects (321 females and 233 males) at a mean age of 21.2 years (range 20–23). The optimal number of clusters was determined to be five (minimum BIC-value and a p-value of 0.011 in the LRT test).

<table>
<thead>
<tr>
<th>Muscle strength parameter</th>
<th>2.5%</th>
<th>25 %</th>
<th>50%</th>
<th>75%</th>
<th>97.5%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Men</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extension</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absolute (kg)</td>
<td>47.00</td>
<td>78.60</td>
<td>94.10</td>
<td>107.00</td>
<td>140.20</td>
</tr>
<tr>
<td>Weight-related</td>
<td>0.77</td>
<td>1.07</td>
<td>1.25</td>
<td>1.44</td>
<td>1.90</td>
</tr>
<tr>
<td>Flexion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absolute (kg)</td>
<td>35.20</td>
<td>57.13</td>
<td>69.25</td>
<td>83.28</td>
<td>121.00</td>
</tr>
<tr>
<td>Weight-related</td>
<td>0.48</td>
<td>0.76</td>
<td>0.91</td>
<td>1.13</td>
<td>1.61</td>
</tr>
<tr>
<td>Rotation left</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absolute (kg)</td>
<td>8.90</td>
<td>19.10</td>
<td>25.60</td>
<td>33.80</td>
<td>48.90</td>
</tr>
<tr>
<td>Weight-related</td>
<td>0.13</td>
<td>0.26</td>
<td>0.34</td>
<td>0.43</td>
<td>0.66</td>
</tr>
<tr>
<td>Rotation right</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absolute (kg)</td>
<td>10.10</td>
<td>19.25</td>
<td>25.65</td>
<td>32.50</td>
<td>47.10</td>
</tr>
<tr>
<td>Weight-related</td>
<td>0.14</td>
<td>0.27</td>
<td>0.34</td>
<td>0.43</td>
<td>0.62</td>
</tr>
<tr>
<td>Extensor - flexor ratio</td>
<td>0.78</td>
<td>1.17</td>
<td>1.35</td>
<td>1.54</td>
<td>2.12</td>
</tr>
<tr>
<td>Left to right rotation ratio</td>
<td>0.54</td>
<td>0.83</td>
<td>0.99</td>
<td>1.20</td>
<td>1.78</td>
</tr>
</tbody>
</table>

1 Weight-related values are calculated by dividing Absolute values with body weight.
Table 6 represents the prevalence of LBP and functional limitations in each of the five clusters at 18, 19 and 21 years. Cluster “1” (hereafter “Always Painful”) includes the subjects who had high likelihood of LBP and functional limitation at all time points (e.g., 72% had consulted a physician at 18 years and 87% at 21 years; Table 1). Cluster 2 (“Recent Onset Pain”) includes subjects with no consequences of pain (pain medication, physician consultation) or functional limitations at 18 years, intermediate at 19 years and high likelihood at 21 years; cluster 3 (“Moderately Painful”) subjects with intermediate likelihood of consequences of pain and functional limitations at all time points; cluster 4 (“Minor Pain”) subjects with high likelihood of LBP during the past six months at 18, 19 and 21 years, and with low likelihood of pain consequences and functional limitations at all time points; whereas cluster 5 (“No Pain”) includes subjects with low likelihood of LBP during the past six months, and with no pain consequences or functional limitations at any time points; i.e. subjects in the "No Pain" cluster are virtually asymptomatic. (Table 6)

Table 6. Low back symptoms in the six clusters at the age of 18 and 20 years in study participants at the age of 18 and at the age of 20 (N=874).

<table>
<thead>
<tr>
<th>LCA groups</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>At 18 years</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ever LBP</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>0.009</td>
<td>0.000</td>
</tr>
<tr>
<td>N</td>
<td>93</td>
<td>139</td>
<td>230</td>
<td>120</td>
<td>117</td>
<td>173</td>
</tr>
<tr>
<td>LBP during the past 6 months</td>
<td>0.892</td>
<td>0.950</td>
<td>0.870</td>
<td>0.850</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>N</td>
<td>93</td>
<td>139</td>
<td>230</td>
<td>120</td>
<td>119</td>
<td>173</td>
</tr>
<tr>
<td>Daily activities restricted</td>
<td>0.645</td>
<td>0.341</td>
<td>0.074</td>
<td>0.148</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>N</td>
<td>93</td>
<td>129</td>
<td>189</td>
<td>81</td>
<td>117</td>
<td>173</td>
</tr>
<tr>
<td>Sports restricted</td>
<td>0.856</td>
<td>0.473</td>
<td>0.326</td>
<td>0.333</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>N</td>
<td>90</td>
<td>129</td>
<td>190</td>
<td>81</td>
<td>117</td>
<td>173</td>
</tr>
<tr>
<td>Visited a doctor</td>
<td>0.767</td>
<td>0.126</td>
<td>0.016</td>
<td>0.013</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>N</td>
<td>90</td>
<td>127</td>
<td>191</td>
<td>78</td>
<td>117</td>
<td>173</td>
</tr>
</tbody>
</table>
The scores of the included dichotomized (no vs. yes) pain variables at a given age. The scores within groups range from 0 (no one in the group had pain symptoms) to a maximum of 1 (all subjects in the group had pain symptoms).

### LCA groups

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Used painkillers</strong> (^f)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.791</td>
<td>0.380</td>
<td>0.089</td>
<td>0.141</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>N</td>
<td>90</td>
<td>129</td>
<td>192</td>
<td>78</td>
<td>117</td>
<td>173</td>
</tr>
<tr>
<td><strong>Intense LBP</strong> (^g)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.925</td>
<td>0.554</td>
<td>0.062</td>
<td>0.148</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>N</td>
<td>93</td>
<td>130</td>
<td>193</td>
<td>81</td>
<td>117</td>
<td>173</td>
</tr>
<tr>
<td><strong>LBP episode</strong> (^h)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.544</td>
<td>0.102</td>
<td>0.005</td>
<td>0.051</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>N</td>
<td>90</td>
<td>127</td>
<td>190</td>
<td>79</td>
<td>117</td>
<td>173</td>
</tr>
</tbody>
</table>

### At 20 years

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ever LBP</strong> (^a)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>0.100</td>
<td>1.000</td>
<td>0.069</td>
</tr>
<tr>
<td>N</td>
<td>93</td>
<td>139</td>
<td>230</td>
<td>120</td>
<td>119</td>
<td>173</td>
</tr>
<tr>
<td><strong>LBP during the past 6 months</strong> (^b)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.763</td>
<td>0.906</td>
<td>0.760</td>
<td>0.025</td>
<td>0.941</td>
<td>0.000</td>
</tr>
<tr>
<td>N</td>
<td>93</td>
<td>139</td>
<td>229</td>
<td>120</td>
<td>119</td>
<td>173</td>
</tr>
<tr>
<td><strong>Daily activities restricted</strong> (^c)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.652</td>
<td>0.522</td>
<td>0.030</td>
<td>0.000</td>
<td>0.181</td>
<td>0.000</td>
</tr>
<tr>
<td>N</td>
<td>92</td>
<td>134</td>
<td>198</td>
<td>120</td>
<td>94</td>
<td>173</td>
</tr>
<tr>
<td><strong>Sports restricted</strong> (^d)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.815</td>
<td>0.559</td>
<td>0.256</td>
<td>0.000</td>
<td>0.330</td>
<td>0.000</td>
</tr>
<tr>
<td>N</td>
<td>92</td>
<td>135</td>
<td>203</td>
<td>120</td>
<td>97</td>
<td>173</td>
</tr>
<tr>
<td><strong>Visited a doctor</strong> (^e)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.871</td>
<td>0.255</td>
<td>0.000</td>
<td>0.008</td>
<td>0.093</td>
<td>0.000</td>
</tr>
<tr>
<td>N</td>
<td>93</td>
<td>137</td>
<td>201</td>
<td>120</td>
<td>97</td>
<td>173</td>
</tr>
<tr>
<td><strong>Used Painkillers</strong> (^f)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.849</td>
<td>0.518</td>
<td>0.035</td>
<td>0.008</td>
<td>0.292</td>
<td>0.000</td>
</tr>
<tr>
<td>N</td>
<td>93</td>
<td>137</td>
<td>202</td>
<td>120</td>
<td>96</td>
<td>173</td>
</tr>
<tr>
<td><strong>Intense LBP</strong> (^g)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.892</td>
<td>0.686</td>
<td>0.089</td>
<td>0.008</td>
<td>0.292</td>
<td>0.000</td>
</tr>
<tr>
<td>N</td>
<td>93</td>
<td>137</td>
<td>203</td>
<td>120</td>
<td>96</td>
<td>173</td>
</tr>
<tr>
<td><strong>LBP episode</strong> (^h)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.495</td>
<td>0.150</td>
<td>0.010</td>
<td>0.000</td>
<td>0.043</td>
<td>0.000</td>
</tr>
<tr>
<td>N</td>
<td>91</td>
<td>133</td>
<td>198</td>
<td>120</td>
<td>94</td>
<td>172</td>
</tr>
</tbody>
</table>

The scores of the included dichotomized (no vs. yes) pain variables at a given age. The scores within groups range from 0 (no one in the group had pain symptoms) to a maximum of 1 (all subjects in the group had pain symptoms).

- \(^a\) Low back pain (LBP) at some point during lifetime or
- \(^b\) LBP during the past 6 months,
- \(^c\) LBP had restricted daily activities or
- \(^d\) LBP had restricted participation in sports,
- \(^e\) the subject had to consult a physician due to LBP,
- \(^f\) the subject had taken pain killers for LBP,
- \(^g\) worst LBP episode was at least 3 on a 10-point numerical scale and
- \(^h\) at least one episode (current or previous) had lasted for more than 2 weeks.
Table 7. Prevalence of low back symptoms and functional limitations among study subjects in the obtained five Latent Class Analysis clusters at the age of 18, 19 and 21 years. The LCA-analysis was based on all of the listed variables. # The names of the clusters are used for convenience in order to ease their interpretation.

<table>
<thead>
<tr>
<th>LBP symptoms and functional limitations</th>
<th>Always Painful</th>
<th>Recent Onset Pain</th>
<th>Moderate Pain</th>
<th>Minor Pain</th>
<th>No Pain</th>
</tr>
</thead>
<tbody>
<tr>
<td>At 18 years</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LBP during the past 6 months*</td>
<td>0.91</td>
<td>0.46</td>
<td>0.95</td>
<td>0.70</td>
<td>0.24</td>
</tr>
<tr>
<td>Daily activities restricted†</td>
<td>0.54</td>
<td>0.00</td>
<td>0.51</td>
<td>0.08</td>
<td>0.01</td>
</tr>
<tr>
<td>Sports restricted‡</td>
<td>0.79</td>
<td>0.06</td>
<td>0.52</td>
<td>0.34</td>
<td>0.01</td>
</tr>
<tr>
<td>Physician consultation§</td>
<td>0.72</td>
<td>0.00</td>
<td>0.20</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>Pain medication use</td>
<td></td>
<td></td>
<td>0.79</td>
<td>0.06</td>
<td>0.41</td>
</tr>
<tr>
<td>LBP intensity**</td>
<td>0.79</td>
<td>0.00</td>
<td>0.73</td>
<td>0.08</td>
<td>0.01</td>
</tr>
<tr>
<td>LBP episode††</td>
<td>0.60</td>
<td>0.02</td>
<td>0.11</td>
<td>0.02</td>
<td>0.00</td>
</tr>
<tr>
<td>At 19 years</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LBP during the past 6 months*</td>
<td>0.79</td>
<td>0.84</td>
<td>0.89</td>
<td>0.59</td>
<td>0.14</td>
</tr>
<tr>
<td>Daily activities restricted†</td>
<td>0.59</td>
<td>0.27</td>
<td>0.57</td>
<td>0.06</td>
<td>0.00</td>
</tr>
<tr>
<td>Sports restricted‡</td>
<td>0.79</td>
<td>0.58</td>
<td>0.54</td>
<td>0.22</td>
<td>0.00</td>
</tr>
<tr>
<td>Physician consultation§</td>
<td>0.84</td>
<td>0.25</td>
<td>0.25</td>
<td>0.02</td>
<td>0.00</td>
</tr>
<tr>
<td>Used pain medication use</td>
<td></td>
<td></td>
<td>0.93</td>
<td>0.33</td>
<td>0.43</td>
</tr>
<tr>
<td>LBP intensity**</td>
<td>0.90</td>
<td>0.40</td>
<td>0.65</td>
<td>0.12</td>
<td>0.00</td>
</tr>
<tr>
<td>LBP episode††</td>
<td>0.49</td>
<td>0.12</td>
<td>0.17</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>At 21 years</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LBP during the past 6 months*</td>
<td>0.84</td>
<td>0.95</td>
<td>0.92</td>
<td>0.73</td>
<td>0.16</td>
</tr>
<tr>
<td>Daily activities restricted†</td>
<td>0.66</td>
<td>0.70</td>
<td>0.51</td>
<td>0.10</td>
<td>0.00</td>
</tr>
<tr>
<td>Sports restricted‡</td>
<td>0.77</td>
<td>0.57</td>
<td>0.52</td>
<td>0.24</td>
<td>0.01</td>
</tr>
<tr>
<td>Physician consultation§</td>
<td>0.87</td>
<td>0.72</td>
<td>0.16</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>Pain medication use</td>
<td></td>
<td></td>
<td>0.99</td>
<td>0.83</td>
<td>0.38</td>
</tr>
<tr>
<td>LBP intensity**</td>
<td>0.84</td>
<td>0.86</td>
<td>0.64</td>
<td>0.15</td>
<td>0.00</td>
</tr>
<tr>
<td>LBP episode††</td>
<td>0.54</td>
<td>0.37</td>
<td>0.11</td>
<td>0.01</td>
<td>0.00</td>
</tr>
</tbody>
</table>

The score of the included dichotomized pain variables at a given age. The scores within groups range from 0 (no one in the cluster had pain or functional limitations) to a maximum of 1 (all subjects in the cluster had pain or functional limitations); * Number of subjects differs from the final number of subjects analysed (563 vs. 554) due to missing MRI data; †LBP during the past 6 months; ‡LBP had restricted daily activities; §LBP had restricted participation in sports; ¶The subject had consulted a physician because of LBP; ||The subject had taken pain medication because of LBP; **The intensity of the worst LBP episode was at least 3 on a 10-point numerical rating scale; ††At least one episode of LBP (current or previous) had lasted for more than 2 weeks.
5.6 Low back symptoms in relation to trunk muscles and body sway

The results of isometric trunk muscle strength and body sway in different LCA subgroups are presented in Table 7. No statistically significant differences were found between the clusters in any of the variables. The results did not differ by gender in any of the measured variables (p-values from 0.051 to 0.872). The cluster with the most severe low back symptoms (cluster 1) tended to perform slightly better in isometric trunk muscle strength tests than the other groups (adjusted odds ratios ranged from 1.05 to 1.32.) The asymptomatic group (cluster 6) tended to have higher extension-flexion ratio than the other groups as the adjusted OR in the other groups ranged from 0.78 to 0.91. In the body sway tests, the most symptomatic cluster "1" tended to have a bigger body sway area when standing with eyes open (OR 1.48; 0.98–2.24).

The mean CSAs of the erector spinae and multifidus muscles in the total population and in each pain cluster are presented in Table 8. The cluster with no pain was used as reference group. Cross-sectional areas were significantly larger in men than women (p<0.001). The mean CSA of the erector spinae was approximately 33% larger in men, while the CSA of multifidi was approximately 35% larger in men (Table 8). There were no differences in the CSAs of the measured muscles between the left and the right side. The CSAs of the erector spinae and multifidi did not differ between the pain clusters (Table 8).

The results of the fat content measurements are presented in Table 9. The cluster with no pain was used as a reference group. The fat content of the multifidus muscles was significantly higher in women than in men (P-values for all gender differences <0.001). The fat content of the multifidus muscles did not differ between the pain clusters.

Analyses of trunk muscle strength and body sway were also conducted with the five subgroups formed for study IV in order to find possible differences between these subgroups. However, no significant differences were found (data not shown). Neither was there any difference in muscle CSA or fat content between the six subgroups of study II.
Table 8. Standardized odd ratios (OR) in LCA subgroups for having one standard deviation (SD) change in the response variable (trunk extension, trunk flexion, rotation left and right, extension-flexion ratio, body sway area and velocity eyes open and closed; n=874).

<table>
<thead>
<tr>
<th>Muscle strength and body sway parameters</th>
<th>SD</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
<th>Group 5</th>
<th>Group 6</th>
<th>p for sex interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n=93</td>
<td>n=139</td>
<td>n=230</td>
<td>n=120</td>
<td>n=119</td>
<td>n=173</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>OR (95% CI)</td>
<td>OR (95% CI)</td>
<td>OR (95% CI)</td>
<td>OR (95% CI)</td>
<td>OR (95% CI)</td>
<td>OR (95% CI)</td>
<td>OR</td>
<td></td>
</tr>
<tr>
<td>Trunk extension</td>
<td>0.38</td>
<td>1.05 (0.58 1.92)</td>
<td>0.80 (0.51 1.27)</td>
<td>0.88 (0.58 1.35)</td>
<td>0.65 (0.41 1.03)</td>
<td>0.66 (0.41 1.05)</td>
<td>1.00</td>
<td>p=0.827</td>
</tr>
<tr>
<td>Trunk flexion</td>
<td>0.48</td>
<td>1.32 (0.78 2.25)</td>
<td>1.05 (0.68 1.60)</td>
<td>0.98 (0.67 1.44)</td>
<td>0.90 (0.58 1.41)</td>
<td>0.83 (0.53 1.29)</td>
<td>1.00</td>
<td>p=0.468</td>
</tr>
<tr>
<td>Rotation left</td>
<td>0.57</td>
<td>1.29 (0.75 2.23)</td>
<td>1.03 (0.67 1.59)</td>
<td>1.00 (0.68 1.47)</td>
<td>0.82 (0.53 1.27)</td>
<td>0.87 (0.56 1.36)</td>
<td>1.00</td>
<td>p=0.641</td>
</tr>
<tr>
<td>Rotation right</td>
<td>0.52</td>
<td>1.30 (0.77 2.21)</td>
<td>0.97 (0.64 1.47)</td>
<td>1.00 (0.69 1.45)</td>
<td>0.90 (0.59 1.37)</td>
<td>0.95 (0.62 1.46)</td>
<td>1.00</td>
<td>p=0.872</td>
</tr>
<tr>
<td>Extension-flexion ratio</td>
<td>0.27</td>
<td>0.78 (0.53 1.16)</td>
<td>0.84 (0.61 1.17)</td>
<td>0.95 (0.71 1.26)</td>
<td>0.82 (0.59 1.15)</td>
<td>0.91 (0.65 1.27)</td>
<td>1.00</td>
<td>p=0.674</td>
</tr>
<tr>
<td>EO velocity</td>
<td>0.30</td>
<td>1.35 (0.88 2.07)</td>
<td>1.10 (0.78 1.55)</td>
<td>0.99 (0.73 1.35)</td>
<td>1.13 (0.79 1.61)</td>
<td>1.10 (0.77 1.57)</td>
<td>1.00</td>
<td>p=0.575</td>
</tr>
<tr>
<td>EO area</td>
<td>0.30</td>
<td>1.48 (0.98 2.24)</td>
<td>1.06 (0.77 1.48)</td>
<td>0.89 (0.67 1.20)</td>
<td>1.13 (0.81 1.59)</td>
<td>0.92 (0.66 1.28)</td>
<td>1.00</td>
<td>p=0.051</td>
</tr>
<tr>
<td>EC velocity</td>
<td>0.31</td>
<td>1.09 (0.72 1.63)</td>
<td>1.16 (0.83 1.61)</td>
<td>1.13 (0.84 1.51)</td>
<td>1.02 (0.73 1.43)</td>
<td>1.04 (0.74 1.46)</td>
<td>1.00</td>
<td>p=0.340</td>
</tr>
<tr>
<td>EC area</td>
<td>0.57</td>
<td>0.94 (0.64 1.39)</td>
<td>0.96 (0.70 1.32)</td>
<td>0.97 (0.73 1.28)</td>
<td>0.98 (0.71 1.35)</td>
<td>0.96 (0.69 1.33)</td>
<td>1.00</td>
<td>p=0.768</td>
</tr>
</tbody>
</table>

Adjusted for height (cm), weight (kg), smoking, physical activity and daily sedentary hours

a EO velocity indicates average body sway velocity (cm/s) with subject standing with eyes open, and area indicates total area (cm²) of the sway. EC values indicate the same parameters with eyes closed.
Table 9. Cross-sectional areas (mm²) of the erector spinae and multifidus muscles in the Latent Class Analysis clusters in young adults (n=554). The values are mean (95% CI) for the "No pain" cluster and mean difference (95% CI) in comparison to the "No pain" reference cluster for other clusters.

<table>
<thead>
<tr>
<th>Variable</th>
<th>None</th>
<th>Minor</th>
<th>Moderate</th>
<th>Recent onset</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men</td>
<td>n</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erector spinae dx</td>
<td>2876 (2778, 2974)</td>
<td>73 (-91, 238)</td>
<td>39 (-197, 275)</td>
<td>64 (-175, 304)</td>
<td>7 (-205, 219)</td>
</tr>
<tr>
<td>Erector spinae sin</td>
<td>2886 (2784, 2988)</td>
<td>66 (-105, 237)</td>
<td>59 (-186, 303)</td>
<td>94 (-155, 342)</td>
<td>35 (-184, 255)</td>
</tr>
<tr>
<td>Multifidus dx</td>
<td>793 (758, 828)</td>
<td>-59 (-130, 12)</td>
<td>9 (-80, 98)</td>
<td>-6 (-96, 85)</td>
<td>-8 (-91, 75)</td>
</tr>
<tr>
<td>Multifidus sin</td>
<td>799 (762, 836)</td>
<td>-45 (-116, 26)</td>
<td>15 (-74, 103)</td>
<td>-18 (-109, 73)</td>
<td>-3 (-86, 80)</td>
</tr>
<tr>
<td>Women</td>
<td>n</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erector spinae dx</td>
<td>2154 (2097, 2210)</td>
<td>52 (-48, 151)</td>
<td>-13 (-140, 113)</td>
<td>51 (-93, 194)</td>
<td>45 (-101, 191)</td>
</tr>
<tr>
<td>Erector spinae sin</td>
<td>2173 (2118, 2229)</td>
<td>69 (-44, 182)</td>
<td>-17 (-162, 128)</td>
<td>52 (-113, 216)</td>
<td>68 (-100, 235)</td>
</tr>
<tr>
<td>Multifidus dx</td>
<td>583 (561, 606)</td>
<td>-4 (-43, 36)</td>
<td>-21 (-71, 28)</td>
<td>16 (-39, 72)</td>
<td>-13 (-70, 44)</td>
</tr>
<tr>
<td>Multifidus sin</td>
<td>582 (561, 604)</td>
<td>-3 (-40, 34)</td>
<td>-29 (-76, 18)</td>
<td>15 (-37, 67)</td>
<td>-12 (-66, 42)</td>
</tr>
</tbody>
</table>

Table 10. Signal loss (%)† in OP images due to fat content of multifidus muscles in Latent Class Analysis clusters in young adults (n=387) The values are mean (95% CI) for the "No pain" cluster and mean difference (95% CI) in comparison to the "No pain" reference cluster for other clusters.

<table>
<thead>
<tr>
<th>Variable</th>
<th>None</th>
<th>Minor</th>
<th>Moderate</th>
<th>Recent Onset</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men</td>
<td>n</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multifidus dx</td>
<td>5.6 (4.3, 6.1)</td>
<td>-0.2 (-3.2, 2.8)</td>
<td>-3.1 (-6.8, 0.6)</td>
<td>-1.3 (-5.1, 2.5)</td>
<td>1.5 (-2.0, 5.0)</td>
</tr>
<tr>
<td>Multifidus sin</td>
<td>5.6 (4.2, 7.0)</td>
<td>-0.6 (-3.5, 2.4)</td>
<td>-2.7 (-6.4, 0.9)</td>
<td>0.7 (-3.1, 4.4)</td>
<td>1.6 (-1.8, 5.0)</td>
</tr>
<tr>
<td>Women</td>
<td>n</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multifidus dx</td>
<td>14.3 (13.0, 15.6)</td>
<td>-1.4 (-3.9, 1.2)</td>
<td>-0.9 (-4.1, 2.3)</td>
<td>2.7 (-0.9, 6.2)</td>
<td>-1.54 (-5.2, 2.1)</td>
</tr>
<tr>
<td>Multifidus sin</td>
<td>14.3 (12.9, 15.8)</td>
<td>-0.5 (-3.2, 2.3)</td>
<td>-0.5 (-4.0, 3.0)</td>
<td>2.2 (-1.7, 6.1)</td>
<td>-1.0 (-5.0, 2.9)</td>
</tr>
</tbody>
</table>

† Relative difference between the intensities of the IP and OP images was calculated with the formula: (IP-OP)/IP*100%. The more the (muscle) tissue contains fat, the more it loses signal intensity in OP images.
5.7 Muscular fitness in relation to physical activity and TV viewing

The males reported higher physical activity than females at the age of 19 (p<0.001), but there was no significant gender difference in the time spent watching TV (p=0.141) (Table 1). Twenty-one percent of males and 7% of females reported participation in MVPA at least seven hours a week, while 28% and 41% participated in MVPA less than two hours per week, respectively. Fifty-four percent of the females and 49% of the males reported watching TV two hours or more per day (Table 1).

The two most active female subgroups performed significantly better than those in the lowest activity category in almost all muscle strength tests (Fig. 11). Furthermore, females who participated 2–3 hours a week in MVPA performed slightly better than the least active group, although these differences were not statistically significant (p-values varied from 0.076 to 0.761). In the counter-movement jump test the females in the lowest activity category had the lowest measured values (p=0.005) (Fig. 11d).

Trunk muscle strength was better in the most active category compared to the least active category of males (p<0.022). The two other active groups of males also performed slightly better than the least active group, but significant differences were observed only in trunk extension for the group exercising 4–6 hours a week (p=0.022). (Fig. 12) In the countermovement jump the two most active groups performed better than the reference group (p<0.001) (Fig. 12d).

The mean differences in muscular fitness variables between the activity and TV viewing groups are also presented in Fig. 12. The females who watched TV for two hours or more daily had lower muscular fitness compared to those who watched TV less than two hours, independently of the level of physical activity. The difference was significant for all fitness variables (p-value from 0.01 to <0.001) except for left rotation (p=0.06). Similarly, the males who spent most time watching TV performed significantly worse in trunk extension (p=0.033) and flexion tests (p=0.009). The same trend was evident in other tests, although the difference was not significant.
Fig. 15. Muscular fitness according to the level of physical activity and TV viewing in Finnish young adults (n=874) according to analysis of variance adjusted for body weight, height and smoking. The results for muscular fitness and MVPA are also adjusted for TV viewing, and the results for the muscular fitness and TV viewing are adjusted for MVPA. Mean differences (95% confidence intervals) compared to the reference group are presented. MVPA (moderate-to-vigorous intensity physical activity) 1) less than 2 hours, 2) 2–3 hours, 3) 4–6 hours, and 4) 7 hours or more per week. TV (television viewing) 1) less than 2 hours and 2) 2 hours or more per day.
6 Discussion

6.1 Main findings

Reproducibility of isometric trunk muscle testing was found to be comparable to other methods that are used to measure trunk muscle function. Low back symptoms were not associated with postural balance or trunk muscle strength. Neither was there an association between LBP and the cross-sectional area or fat content of the lumbar muscles. Trunk muscles were significantly stronger in those who participated in regular physical activity and weaker in those who watched TV more than two hours daily.

In conclusion, physical activity has a positive association with muscular fitness whereas the association with TV viewing is negative independently of the level of physical activity. Single measurement of trunk muscle strength and the cross-sectional area or fat content of lumbar extensor muscles has little significance in the evaluation of the severity of low back symptoms.

In this study, low back pain was common among young adults. Lifetime prevalence was similar in both genders, but females reported pain more frequently during the last six months than males. Reproducibility of isometric trunk muscle testing was found to be comparable to other methods in use for assessing performance capacity such as isokinetic muscle strength testing. Inclinometric testing device was found to offer a valid method to assess body sway as the portable and low-cost device provides real-time information on the absolute movements of the body.

Latent class analysis divided subjects into five (study IV) or six (study II) clusters in which individuals had similar pain profiles. The profiles varied from virtually asymptomatic subjects to those who had continuous LBP. Despite the clear difference in severity of symptoms between the clusters, there was no significant difference in trunk muscle strength or body sway. Furthermore, no significant difference was found in CSA or fat content of the lumbar muscles between the low back symptom clusters.

Males participated in physical activity more intensively than females whereas there was no significant difference in TV viewing between the genders. In both genders those who participated most actively in MVPA performed better in muscle strength test whereas those whose activity was lowest had the worst muscle performance. In both genders, the subjects watching TV more than two
hours daily had significantly poorer muscle strength than those watching less TV, independently of the level of physical activity.

### 6.2 Methodology

The population of this study consisted of all the 2,969 men and women who had had an expected date of birth between July 1, 1985 and June 30, 1986 in the two northernmost provinces of Finland, Oulu and Lapland, and who were living within a one-hundred kilometre radius of the city of Oulu in autumn 2003. 68% (1,987) of the population answered the postal questionnaire and were invited to further examinations. A total of 874 young adults participated in physical examinations and 554 young adults participated in lumbar MRI examinations.

The main strength of this study lies in its population-based birth cohort design. The study population was a large, representative sample of young adults. So far this is the largest population-based study in which isometric trunk muscle performance has been accurately measured. Furthermore, lumbar MRI was conducted with remarkably large sample size.

However, several limitations need to be considered. The main limitation is the cross-sectional design of physical examinations and spine imaging, which prevents drawing conclusions about temporal patterns between low back symptoms and paraspinal muscle characteristics. Furthermore, due to the study design, there is the possibility of reverse causality, viz. poor muscular fitness due to any reason could potentially modify the reporting of physical activity and inactivity. Although this may, in theory, partly explain the results, we are inclined to believe that the level of physical activity or inactivity determines muscular fitness.

As a major limitation, pain and disability assessment were based on self-reports. However, very few studies have assessed the “objective” consequences of back-related diseases, such as hospitalization rates. Moreover, their use as outcome variables in LBP studies is problematic. Social class, availability of hospital care, subjective attitudes of physicians, and even local treatment guidelines and practices can affect the rates (Szpalski et al. 1995). The validity of the pain questionnaire has previously been concluded to be comparable to interview (Staes et al. 2000). LBP outcome has been validated against lumbar degenerative magnetic resonance imaging (MRI) findings and recurrent LBP symptoms among young adults (Salminen et al. 1999). The pain questionnaire used in the present study did not specifically differentiate menstruation pain from
other types of LBP among girls, which may partly explain the higher prevalence of "Reporting LBP" among girls. Since the self-reporting of LBP is prone to recall bias and the definitions of LBP contain a great deal of variation, we decided to include back-related activity limitations (disability) items, in addition to pain symptoms, in the clustering of the subjects. As a method, the LCA analysis used in this study is recognized as a useful tool in locating homogenous subgroups with respect to certain variables (Formann & Kohlmann 1996). The LCA analysis revealed between studies II and IV two slightly different combinations of variables used to find similar subgroups. The number of the subgroups was different (6 in study II vs. 5 in study IV). This is due to slightly different study samples between the studies as all of the subjects who participated in physical examinations did not participate in MRI examination. Additionally, in study II 18- and 19-year data was used in contrast to 18-, 19- and 21-year data in study IV. However, this should not have any significant impact on the results since the analyses were also conducted for muscle CSA and fat content with six clusters of study II and vice versa, and no significant differences were found.

The estimations of physical activity and TV viewing were based on self-reports. Objective measurements, such as accelerometers for the assessment of physical activity, would have been a more accurate method. However, such measurements were not available at the time of the study and it would have been almost impossible to perform objective measurement of activity in such a large cohort as ours. Social desirability bias may lead to over-reporting of physical activity (Sallis et al. 2000). However, the test-retest reliability of physical activity questions as described by percentage agreement values was substantial, as evaluated previously (Tammelin et al. 2007).

A “healthy worker effect” might be present if young adults with worse health level had not responded. This potential bias would underestimate the associations as the respondents would be healthier, and possibly have better fitness than non-respondents. Low response rate is also a possible weakness of the study, as 29% of the cohort was examined. Selection bias in this cohort has been evaluated before (Mikkonen et al. 2008). The respondents in the 18-year survey (n=1,987) were more likely to be living in two-parent families and the participating girls were slimmer and more often non-smokers than those lost to follow-up. Furthermore, males who participated in MRI examinations had a slightly higher prevalence of LBP compared to the original population (Takatalo et al. 2009). Among those who were invited to lumbar MRI (n=874), the characteristics of the
participants did not differ from non-participants. Thus, there was some selection bias, but its impact on the generalizability of the results is likely to be minimal.

### 6.3 Prevalence of low back pain and sciatica

Differing methods of diagnosing and classifying LBP explain most of the variation in pain prevalence across previous studies, but also cultural differences in health beliefs and reporting health problems vary between populations. In our study the lifetime prevalence of LBP and sciatica were found to be slightly higher than in previous studies among children or adolescents (Balague et al. 1999, Harreby et al. 1999). The results may be explained with the slightly older age of the subjects in this study. A significant difference between genders was found only in the six-month prevalence of "Reporting LBP", which is in contrast with previous studies reporting higher lifetime prevalence among girls (Harreby et al. 1999, Watson et al. 2003). As previous authors have proposed, the difference may be due to the fact that the question on six-month prevalence of LBP did not account for possible menstruation pains, which may partly explain the higher prevalence of mild LBP in girls (Harreby et al. 1999).

### 6.4 Reproducibility of the measurements

As there are no definite cut-off values for ICC (Atkinson & Nevill 1998), many different interpretations have been presented. Some studies have adopted classification for κ (Landis & Koch 1977), where values below 0.20 indicate poor agreement, values between 0.21 and 0.40 fair, values between 0.41 and 0.60 moderate, values between 0.61 and 0.80 substantial and values over 0.81 almost perfect agreement. The Scientific Advisory Committee of The Medical Outcomes Trust considers ICC values 0.70 and higher satisfactory for group comparisons (SAC 2002), and this view has been adopted by some authors (DeWinter et al. 2004). In some other studies (Atkinson & Nevill 1998, Rankin & Stokes 1998) values between 0.80 and 0.90 have been considered good and values over 0.90 excellent. In this study we considered values over 0.70 acceptable.

In our study, the intra-rater reproducibility of the isometric trunk muscle strength measurements was very good, as ICC values ranged from 0.84 to 0.94. Inter-rater reproducibility was also good, with ICC values from 0.84 to 0.88. Our results are in agreement with the results of a previous study (Karatas et al. 2002), where the intra- and inter-rater reliability of the isokinetic trunk muscle strength
measurement was evaluated. ICC values of the measurements varied between 0.80 and 0.98. Our results show a somewhat higher reproducibility than a previous study concerning the inter-rater reliability of abdominal and trunk extensor dynamic endurance, hand held dynamometry of isometric flexion and extension, and abdominal and extensor static endurance, where ICC of the hand held isometric trunk muscle strength tests varied between 0.24 and 0.25 (Moreland et al. 1997). However, direct comparison between the studies is difficult due to different methods to measure muscle strength. Methods vary from non-dynamometric tests, such as repeated sit-ups and arch-ups (Alaranta et al. 1994), to advanced isokinetic dynamometers (Karatas et al. 2002).

When testing muscle strength, several factors may possibly affect the reproducibility of a test: the accuracy of the dynamometer, the reproducibility of the test parameters, the test protocol, subject-related factors and motivation. The mechanical accuracy of dynamometers has been assessed in experimental studies and has been found to be high (Osternig 1986), which may explain our better results compared to hand held dynamometry.

As the dynamometer itself is not a probable cause of variation between measurements, the reproducibility of measurements is mostly related to testing conditions and performance of the examiners. The conditions under which the tests are made may not be the same and the examiners may fail to follow test procedures. Wider limits of agreement in the Bland-Altman analysis for inter-rater repeatability compared to intra-rater repeatability may be explained with a different time interval between measurements. The inter-rater measurements were made within one hour, whereas intra-rater measurements were carried out in the course of one week. This was due to practical reasons and makes comparison of intra-rater and inter-rater values a little more difficult. In the trunk extension test-retest measurements, all but one subject performed worse in the latter measurement. This can be explained by a systematic error of performing the measurements with an insufficient time interval in between; the subjects may not have had enough time to recover from the first test. However, in all other trunk strength tests the average values of the latter measurement were better and variation between tests was randomly scattered around zero. It is possible, though unlikely, that differences exist due to different placement of the resting pads. A Finnish study (Rantanen & Nykvist 2000) reported that a more caudal placing of the pelvic support increased measured torque in extension and in flexion. According our experience, tightness of the sternal resting pad is also a significant factor for differences between measurements. Because the study aimed to
evaluate repeatability between two independent measurements, the height and the
tightness of the pads were not recorded, so the settings of the pads were
independent from the other measurements. In follow-up studies, repeatability
could be improved by repeating measurements with the same settings of the pads.
The examiners in this study were not familiar with the dynamometer before the
start of the study. However, they were carefully familiarized to testing by a highly
experienced person before the study. The relative inexperience of the examiners
should therefore not have a major impact on the results.

Subject familiarization before testing is considered necessary to obtain
consistent measurements (Osternig 1986). To optimize reproducibility, two
submaximal warm-up repetitions were allowed before the testing. Another
subject-related factor is motivation. Subjects might not have reached their true
maximal effort because of lack of motivation. Verbal encouragement and visual
feedback during the testing can influence the ability to produce maximum effort
(Keating & Matyas 1996). In our study verbal encouragement was used, and the
testing personnel were carefully educated to standardize their wordings. However,
standardization appeared to be difficult, and for example sound volume varied
somewhat between the examiners, which may have had an impact on the results.

When assessing the reproducibility of the body sway measurements, the ICC
values ranged from 0.39 to 0.74 in the intra-rater reliability analysis, indicating
rather poor reproducibility. In the inter-rater reproducibility tests, ICC indicated
better reliability between the two testers, ranging from 0.61 to 0.85. Poorer ICC
values compared to trunk muscle testing could be partly explained by smaller
variation between subjects, as it has been shown that larger variation between
results of different subjects leads to higher ICC values (Rankin & Stokes 2000).
Comparison to previous studies is not possible due to lack of studies using the
inclinometric method on young, healthy adults. However, values of the Bland-
Altman analysis were similar to the results of a previous study conducted with 51
elderly women (Korpelainen et al. 2005), which also revealed quite a wide range
for limits of agreement. Also a study conducted with stroke patients using a force
platform revealed only moderate reliability (Liston & Brouwer 1996). When
interpreting these results, it should be remembered that postural control is a
complex, dynamic interaction of vestibular, visual and proprioceptive signals
analysed in the central nervous system, resulting in constantly changing motor
outputs. The fluctuating nature of the response variable and momentary individual
balancing body movements may partly explain the variation between the results
(Korpelainen et al. 2005). In conclusion, the inclinometric method to assess body
sway is comparable to the force platform method (Korpelainen et al. 2005), which also seems to have limited reliability (Keating & Matyas 1996). Quite possibly, tests that challenge the postural control system to respond quickly and appropriately with little room for error may be best at differentiating between levels of balance performance.

There is no golden standard to evaluate fat content of the lumbar muscles. We decided to use Opposed-Phase MR Imaging, which is a method used to display and quantify the fat fraction in tissues that contain both water and fat. The technique is useful when water and fat coincide in the same voxel (Gaeta et al. 2008) and it has proved to be a valuable method for assessing fat content of different tissues (Savci et al. 2006). A major advantage of the technique compared to visual analysis is that there is no need for reference tissue and image windowing has no influence on the results. Furthermore, when analysis is based on subtraction instead of qualitative analysis it can also be used by inexperienced users (Savci et al. 2006). In this study reproducibility of the measurements was found to be good. There are no previous studies using this method to estimate the fat content of the lumbar muscles. However, our results are in accordance with a previous study concerning the value of the method diagnostics of adrenal masses (Savci et al. 2006). In the study the kappa value for a definite or probable diagnosis of an adenoma was 0.93 and at the highest (definite) confidence of an adenoma 0.81, indicating excellent interobserver agreement. Furthermore, the authors concluded that the method could be used in equivocal cases or by inexperienced observers to improve their accuracy.

ICC as a sole indicator showed excellent inter- and intraobserver reproducibility in trunk muscle strength testing where biological variation between the subjects was high. Similarly, ICC indicated excellent reproducibility in lumbar MRI examinations. Also in these tests, variation between the subjects was high. On the other hand, in body sway measurements, where variation between the subjects was much smaller, ICC indicated much poorer reproducibility. As pointed out by some authors, ICC or any other correlation measures do not reveal absolute differences between measurements (Atkinson & Nevill 1998, Rankin & Stokes 1998). In our data, the limits of agreement indicated a wide range of measurement error, especially in inter-rater values. For example, the mean value for repeated inter-rater trunk flexion measurements was 68.2 kg, mean difference was -5.6, standard deviation of the difference was 11.9, and LOA ranged from -29.4 to 18.2. Hopkins has demonstrated a simple way to calculate typical error of the measurements by dividing standard deviation of the
differences by $\sqrt{2}$. In this case, a typical error would be 8.4 as an absolute value and 11.9% if expressed as a percentage of its respective mean (Hopkins 2000). Critical error of the measurements can be calculated by multiplying typical error by 2.77 as proposed by Hopkins. In this case critical error would be 33.0%, meaning that only changes greater than this would indicate significant change in performance. Our results are consistent with Madsen, who found critical differences to be more than 20% in isokinetic trunk muscle testing (Madsen 1996). However, our sample sizes for both intra- and inter-rater tests were quite small, which may widen the 95% limits of agreement (Rankin & Stokes). Our subjects had no previous experience of performing maximal isometric contraction of the trunk muscles, which may further explain some of the variation. Because of the large population in our study ($n=874$), multiple sessions were not possible. For future studies, we recommend subjects to have one or two training sessions before testing.

Although ICC analysis indicated good reproducibility, the Bland and Altman analysis revealed quite a wide range of measurement error. Critical difference between repeated measurements is quite large, which limits the value of these tests when assessing individuals or small groups. However, the reproducibility of isometric trunk muscle testing is comparable to other methods currently in use for assessing performance. The inclinometric testing device offers a portable and low-cost method to assess body sway, providing real-time information on the absolute movements of the body. However, there are limitations in the reproducibility of the measurements, which should be noted when using this kind of device.

### 6.5 Reference values of body sway and trunk muscle strength

There are no reference values for inclinometric body sway measurements. However, our results revealed significantly smaller body sway path length in young adults than those reported in elderly persons (Korpelainen et al. 2005). This is in accordance with earlier results (Raymakers et al. 2005, Fujita et al. 2005), which indicate that body sway increases with ageing. The men in our data had higher postural sway when standing than women, which might be explained by the fact that the men were taller than the women. Thus the estimated centre of gravity (the calculation height) was located higher and moved a longer distance in men than in women.
The values of the isometric trunk muscle strength in our cohort of young adults were generally higher compared to those presented by others (Era et al. 1992, Sinaki et al. 1996) On the other hand, the trunk rotation values were lower than the values presented in a study conducted with healthy adults (Stoll et al 2000). The deviations can largely be explained by the different methods used to measure strength in these studies. Moreover, the subjects in the study by Sinaki et al. (1996) were slightly younger and the subjects in the study by Era et al. (1992) older than the subjects in this study. The previous studies were also made with relatively small groups of subjects of a certain age. Our present study was conducted with a remarkably large cohort of young healthy adults, which makes the results generalizable also for future studies.

6.6 Associations with low back symptoms

6.6.1 Low back symptoms and trunk muscle strength

This cross-sectional, population-based study revealed no significant differences in trunk muscle strength or postural stability with respect to the presence or severity of low back symptoms. As review articles point out, several controversial reports on the association between trunk muscle strength and LBP among children or adolescents have been published previously (Balague et al. 1999, Hamberg-van Reenen et al. 2007). The authors of the reviews conclude that there is no clear association between trunk muscle strength and low back pain in children or adolescents. On the other hand, some longitudinal studies reported that good static endurance of the back muscles may prevent occurrence of LBP (Biering-Sorensen 1984, Luoto et al. 1995) and isokinetic trunk muscle strength has been reported to correlate with self-reported disability in certain tasks, such as walking, standing, sitting, and lying in bed among adult LBP patients (Rissanen et al. 1994). Furthermore, good dynamic trunk muscle strength has been suggested to protect against back-related work disability among adults (Rissanen et al. 2002). In contrast to the conclusions of the review, in adolescents, poor trunk extensor strength combined with increased lumbar mobility has been reported to predict LBP (Salminen et al. 1992b).

Our results on the lack of association between low back symptoms (pain and functional limitations) and poor muscle strength are consistent with the review articles and results of the studies by Balagué (Balagué et al. 1993) and Kujala
Furthermore, our results did not indicate a significant association between LBP and extensor-flexor ratio, which is in accordance with recent longitudinal study with Swiss adolescents (Balagué et al. 2010). However, the results are in contrast to the results of a previous longitudinal study reporting that strong back flexors (when compared to extensors) increased the risk for LBP in children (Newcomer & Sinaki 1996). In the same study, children with LBP improved their back flexor strength more than children without LBP during the four-year follow-up.

When considering the results of this and other studies on trunk muscle performance, some facts have to be borne in mind. Firstly, trunk performance tests differ from study to study, e.g. with regard to movements and positions of the trunk. As Latikka et al. (1995) have reported, back extension endurance and isokinetic tests appear to measure very different aspects of muscle function. Therefore, comparing results from different studies is difficult. Furthermore, the majority of the studies are based on a cross-sectional setting. Unfortunately it is not known which, if any, attributes related to muscle function tests clearly affect the risk for back problems. Secondly, it is difficult to measure accurately LBP or disability caused by LBP. The methodology of this study has been discussed in chapter 6.2. Furthermore, previous studies report significant overlapping in measurements with subjects with or without LBP and it is difficult to find any cut-off points between healthy subjects and patients suffering from LBP (Takala & Viikari-Juntura 2000) As Andersen et al. (2006) pointed out, even if an association between muscle performance and LPB is found, it cannot be said whether the weakening of the muscles is the result or the cause of the low back problems. In this study, we did not identify subjects with specific spinal conditions such as lumbar disc herniations. Previous studies have reported of decreased trunk muscle strength in patients with a disc herniation (Ho et al. 2005) and chronic sciatica (Yahia et al. 2010). Thus, we cannot rule out an association of nerve root lesions and muscle properties or performance in this study. However, considering the results of this and previous studies, despite reservations about methodologies, non-specific LBP in youth cannot be attributed in a simplistic way to muscle weakness.

6.6.2 Low back symptoms and postural balance

As previous studies have been conducted in adult populations, little is known about the association between body sway and LBP among adolescents. Our
results are in accordance with a recent study where authors did not find significant differences in body sway between healthy adults and patients with non-specific LBP (Salavati et al. 2009). However, this is in contrast to the majority of previous studies (Hamaoui & Bouisset 2004, Nies & Sinnott 1991, Leinonen et al. 2003). Contrasting results might be partly explained by different methods used in assessing body sway. We used direct inclinometric method to measure body sway whereas the majority of studies have used force platforms, which record ground reaction forces while body sway is calculated indirectly.

In previous studies persons with LBP have been observed to have less refined position sense of the lower back (Gill & Callaghan 1998, Leinonen et al. 2003). This might be caused by feedback error, which would be due to sensory loss at the lumbar level rather than disorder in information processing. Moreover, reweighting of the proprioceptive input by increasing the gain at ankle level seems to have taken place in persons with LBP, so that persons with LBP tend to use an ankle strategy for balance control in quiet standing. LBP seems to lead to reduced activity of the deep spinal muscles, and at the same time the body is stiffened, e.g. trunk muscles are co-contracted (Hodges & Moseley 2003, Brumagne et al. 2004, 2008). This strategy has been described as common during quiet standing, but inadequate when postural demands increase (Brumagne et al. 2004, 2008), particularly when proprioceptive signals from the ankles are challenged, such as standing on an unstable support surface. In their study, Mok et al. (2004) reported that despite poorer capability to succeed in tasks demanding postural control, patients with LBP had smaller body sway than healthy controls. This was concluded to be due to limited use of the hips in maintaining posture. It is possible that increased use of the ankles in maintaining posture leads to increased movement of the centre of pressure, whereas actual body sway at hip level does not increase as much.

Another difference between this and previous studies is the age of the subjects. The previous studies were conducted in adult populations, which per se makes comparisons to the present study difficult. As it has been demonstrated, body sway increases with age (Fujita et al. 2005). A study conducted with young adults (mean age 22.7 years) reported that body sway did not increase in LBP patients compared to healthy controls. However, when the measurements were performed with eyes closed, significantly greater forward inclination was seen in the LBP group (Brumagne et al. 2008 b). The authors concluded that a more forward inclined posture was caused by changed strategies to maintain posture (e.g. increased use of the ankles and stiffening of the body), and is a purposeful
protective mechanism to prevent postural instability, e.g. body sway. Unfortunately, we did not record possible differences in forward inclination. Furthermore, we did not perform measurements of body sway in challenging conditions, such as using unstable surfaces or external disturbance. However, it seems that younger subjects are more capable of maintaining posture despite lumbar back problems.

6.6.3 Low back symptoms and cross-sectional area of the paraspinal muscles

In contrast to previous studies in adults, we found no significant association between low back symptoms and muscle CSA among young adults. A decrease in the cross-sectional area (CSA) of paraspinal muscles has been widely reported to relate with chronic LBP in adults (Danneels et al. 2000, Parkkola et al. 1993). The decrease can reach 10% compared to healthy individuals (Hultman et al. 1993). Furthermore, rapid muscle atrophy in response to immobilization is well documented (Appell 1990). However, the possible mechanisms for these changes are still under debate. Regardless of the mechanisms for the reduced activity, atrophy has been argued to be mediated by changes in neural drive to a muscle (Fitts et al. 2001). Furthermore, neural drive to the multifidus muscle has been presented to be reduced due to an inhibitory process, such as reflex inhibition (Hodges et al. 2006). Reflex inhibition is the reduction in alpha motoneuron excitability as a result of afferent input from joint structures (Stokes & Young 1984). A recent experimental study reported that decrease in multifidus CSA after lumbar disc injury was confined to a single lumbar level and different to changes following denervation (Hodges et al. 2006). The authors conclude that changes cannot be explained by denervation. In conclusion, decrease in muscle CSA and increased fat content of the multifidus muscles may potentially occur due to disuse following reflex inhibitory mechanism (Hodges et al. 2006). Also other mechanisms such as reduced water content (Scholz et al. 1990) and vasoconstriction, e.g. due to changes in sympathetic activity, may explain the changes (Hodges et al. 2006). These changes may be precursors to chronic changes in the paraspinal muscles.

One explanation for contrasting results between this and previous studies may once again be the younger age of the subjects in our study. Atrophy in the paraspinal muscles may accelerate after the thirties, when the prevalence of intervertebral disc degeneration also increases (Cheung et al. 2009). The changes
in multifidus muscles have been reported to be related to degenerative changes in
the lumbar discs (Lee et al. 2008). Furthermore, in female adults, CSA of the
paraspinal, especially of the multifidus muscles was smaller in patients suffering
from lumbar degenerative kyphosis when compared to patients suffering from
chronic low back pain without degenerative findings in the lumbar spine (Kang et
al. 2007). These results suggest that decreased CSA of the paraspinal muscles is
more related to specific disorders, such as lumbar disc injuries, than to non-
specific low back pain, which is the major reason for LBP in young adults. The
CSA of the erector spinae and multifidus muscles have been reported to be
associated with maximal strength (Peltonen et al. 1998). This is in accordance
with our finding that there was no significant association between maximal trunk
muscle strength and low back symptoms.

6.6.4 Low back symptoms and fat content of the multifidus muscles

In contrast to our study, the majority of previous studies have reported increased
fatty infiltration in the paraspinal muscles of the LBP patients. As for decreased
CSA, the mechanism of increased intramuscular fat is not completely understood.
This may be due to altered differentiation of the fibroblasts in response to injury-
induced inflammation (Parkkola & Kornamo 1992). Alternatively, increased
secretion of proinflammatory cytokines may lead to proliferation of adipocytes
(Parkkola & Kornamo 1992). According to an experimental study, an increased
number of adipocytes can be found already three days after disc or nerve injury
(Hodges et al. 2006). The meaning of overweight on lumbar muscles has also
been under debate. Kjaer et al. (2007) did not find a significant association
between BMI and fat content of the lumbar muscles. Furthermore, increased fat
content was found mainly on L5 level and was virtually absent at L3 level. The
authors concluded that if the body fat of obese people would naturally deposit
itself in muscles, one would find increased fat content throughout the back
musculature. In contrast, increased fat content seems to settle at the lowest levels
where most spinal abnormalities tend to cluster (Kjaer et al. 2005). This fact that
increased fat infiltration is mainly found in the perceived back pain problem areas
tends to suggest that LBP indicates muscle changes, and not vice versa (Kjaer et
al. 2007).

The conflicting results between our study and the previous ones may be due
to older subjects in previous studies (Kader et al. 2000, Lee et al. 2008). This is
supported by previous findings suggesting that increased fat infiltration is more
common in older people (Parkkola & Kornamo 1992). In accordance with our study, a previous study with CT imaging found no significant difference in fat deposits between healthy subjects and chronic LPB patients (Danneels et al. 2000). Furthermore, in a large population-based cross-sectional study, significant fat infiltration of multifidus muscles was found in adults suffering from LBP, but not in adolescents (Kjaer et al. 2007). The authors concluded that increased fat content in older age supports the theory that LBP is the cause of muscle degeneration. Furthermore, they concluded that in younger subjects the duration of LBP may be too short to produce fatty infiltration (Kjaer et al. 2007). This conclusion is supported by our results.

In accordance with our study, previous studies report a higher fat content of the paraspinal muscles in females (Kjaer et al. 2007). It seems that the higher proportion of body fat in females is also reflected in the fat content of the paraspinal muscles. This raises the question of whether grading should be different for males and females. In future studies cut-off points, different for men and women, would be useful tools. Contrasting results between previous studies concerning the fat content of the paraspinal muscles may also depend on different techniques used. In the present study Opposed-Phase MR Imaging was used to evaluate the fat content of the paraspinal muscles whereas the majority of previous studies are based on semi-quantitative visual scaling. The methodology of this study is discussed earlier in chapter 6.2. Kjaer et al. (2007) found interobserver reliability of the MRI measurements based on visual scaling to be unsatisfactory, whereas reliability of measurements in our study was found to be good.

6.7 Physical activity, TV viewing and trunk muscle strength

In this study, both low level of physical activity and high time spent watching TV were independently associated with poor muscular fitness in young adults. Not surprisingly, high level of physical activity was associated with good muscular fitness. A new finding was that the time spent watching TV was associated with poor muscular fitness, independently of physical activity level. The observed association between high levels of physical activity and muscular fitness accords with previous studies (Peltonen et al. 1998, Sandler et al. 1991). Among both genders, the most active individuals, who participated in MVPA for more than seven hours weekly, had the best performance in all tests. Furthermore, a dose-response association could be seen, as two other groups also performed better
than the reference group. A similar dose-response association has been reported by Sandler et al. (1991). Previous studies have shown that even moderate levels of physical activity improve muscle strength (Peltonen et al. 1998, Sandler et al. 1991). A recent study where an ice hockey team of 25 boys aged 13 participated in guided resistance training twice a week for 4 months reported that increased physical activity not only increases muscle strength but, in addition, increases spontaneous physical activity outside of training when compared to a control group with a normal exercise programme (Eiholzer et al. 2010). On the other hand, our results contrast with one longitudinal study among schoolboys (Beunen et al. 1992), which found significant differences between active and inactive groups only in upper body muscle endurance. However, the active group exercised less (more than five hours a week) than the most active group in our study, which could explain the difference. Furthermore, the subjects in our study were older, which may also have had an impact on the results.

As pointed out earlier, there are no previous studies concerning the association between TV viewing and muscular performance. Due to cross-sectional design of our study, there are limited possibilities to estimate causality. However, we assume that increased sedentary activities, such as TV viewing, are the cause of poorer muscular performance and not vice versa. The possible mechanism between increased TV viewing and poorer performance remains unclear. As guided training induces spontaneous physical activity, it is possible that excessive TV viewing induces other sedentary activities and reduces activities of daily life, such as biking or walking to school or friends’ houses.
7 Conclusions

In conclusion of the thesis, LBP is a common problem in youth. However, the majority of young adults suffering from LBP have only mild functional limitations. Furthermore, it seems that LBP has little effect on physical capacity or muscles of adolescents and young adults. Our results indicate that there is considerable overlap of maximal isometric trunk muscle strength and inclinometric body sway between subjects with and without LBP. Low back pain does not seem to be associated with maximal isometric trunk muscle strength and body sway in young adults. Furthermore, low back pain and back-related functional limitations over a three-year period were not associated with the fat content or cross-sectional area of lumbar multifidus muscles at the age of 21 years.

Measurements of maximal isometric trunk muscle strength like the cross-sectional area and fat deposit of the paraspinal muscles proved to have good reproducibility. Inclinometric testing device offers a portable and low-cost method to assess body sway, providing real-time information on the absolute movements of the body. Although ICC analysis indicated good reproducibility, the Bland and Altman analysis revealed quite a wide range of measurement error. Critical difference between repeated measurements is quite large, which limits the value of these tests when assessing individuals or small groups. These limitations in the reproducibility of the measurements should be noted when using this device.

The level of physical activity was associated with muscle strength as assumed. However, more interestingly, among young adults, daily TV viewing for two hours or more was associated with poorer muscular fitness, irrespective of physical activity level. The mechanism of this association remains unclear and needs further studies.

This study did not evaluate the association between specific spinal conditions such as disc herniations with or without sciatica and strength or fat content of the lumbar muscles. Further studies are needed for this purpose.

In conclusion, although physical activity has a positive and TV viewing a negative effect on muscular fitness, a single physical measurement such as trunk muscle strength and cross-sectional area or fat content of lumbar extensor muscles has little significance in the evaluation of the severity of low back symptoms. The reason for this dilemma are other risk factors of LBP, such as
psychosocial factors (depression, anxiety), which may alter pain perception or experience.
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Original articles


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1094. Solyom, Szilvia (2011) BRCA/Fanconi anemia pathway genes in hereditary predisposition to breast cancer


1096. Lunnela, Jaana (2011) Internet-perusteisen potilasohjauksen ja sosiaalisen tuen vaikutus glaukoomapotilaan hoitoon sitoutumisessa

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POSTURAL BALANCE, ISOMETRIC TRUNK MUSCLE STRENGTH AND LOW BACK SYMPTOMS AMONG YOUNG ADULTS