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JYVÄSKYLÄN YLIOPISTO

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ABSTRACT

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The objectives were 1) to determine the reliability of the measures of back function related factors, 2) to investigate the possibilities to detect changes in paraspinal muscles, and 3) to study the relative effects of heredity, constitutional and behavioral factors on three back function tests. Paraspinal muscle cross-sectional areas were obtained by magnetic resonance imaging from a sample of 210 men; anthropometric measures, isokinetic and psychophysical lifting capacity, and isometric back extension endurance tests were performed and current and past physical activity during leisure-time and at work were ascertained from a structured interview from a total sample of 600 men who were 35 to 70 years old. The reliability of the lifetime physical activity interview and also the measures of paraspinal muscles CSAs was acceptable. The back function tests measure very different attributes with different determinants, emphasizing the importance of careful test selection. The isokinetic lifting test performance was mainly influenced by heredity i.e. it assesses the physical capacity for lifting, which means that it may prove difficult to alter isokinetic lifting capacity by interventions. Heredity and behavioral factors contributed equally to the psychophysical lifting ability. Anthropometric measures and physical activity parameters exhibited only a weak association with psychophysical lifting capacity, indicating that behavioral factors other than those considered in this study may play more influential roles. The isometric back extension endurance test reflected back health and performance in pain-free subjects, but this test may measure back pain in individuals with a history of LBP. The predictive association of isometric back extension endurance time for future LBP episodes could be enhanced by understanding in greater detail the reasons for test termination.

Keywords: Heredity, back function, paraspinal muscle, muscle cross-sectional area, reproducibility, magnetic resonance imaging, lifting force

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In Kuopio, 7th of February 2006 Annina Ropponen

LIST OF THE ORIGINAL PUBLICATIONS

This thesis is based on the following original articles and manuscript, which are referred to in the text by Roman numerals I–V:

I Ropponen A, Levälahti E, Simonen RL, Videman T, Battié MC. Repeatability of lifetime exercise reporting. Scand J Med Sci Sports. 2001; 11: 185-192.

II Ropponen A, Videman T, Battié MC: The reliability and construct validity of measurements of paraspinal muscles using routine spine MRI. Submitted.

III Ropponen A. Comparison of the roles of common constitutional and behavioural parameters in back function performance estimates. Isokinetics and Exercise Science, in press.

IV Ropponen A, Levälahti E, Videman T, Kaprio J, Battié MC. The role of genetics and environment in isokinetic and psychophysical lifting capacity and isometric trunk extensor endurance. Phys Ther. 2004; 84: 608-621.

V Ropponen A, Gibbons LE, Videman T, Battié MC. Isometric back extension endurance test: reasons for test termination. J Orthop Sports Phys Ther. 2005; 35: 437-442.

In addition, some unpublished data are presented.

ABBREVIATIONS

AIC	Akaike's information criteria
CI	Confidence interval
CSA	Cross-sectional area
CSF	Cerebrospinal fluid
CT	Computed tomography
DZ	Dizygotic
ICC	Intraclass correlation coefficient
LBP	Low back pain (reported pain in the back)
MRI	Magnetic resonance imaging
MZ	Monozygotic

CONTENTS

1 GENERAL INTRODUCTION

The predictive value for return to work after LBP (Gross et al. 2004) or need for rehabilitation (Bendix et al. 1998, Ruan et al. 2001) can be assessed via back function performance, but it is still unclear exactly what the back function tests actually measure. A better understanding of the determinants of back function tests would assist in choosing the correct test and allow more accurate interpretation of the back function tests in evaluating working capacity, investigation of back disorders, as well as being useful in preventive medicine and related to maintenance or enhancement of back muscle function. It should be possible to select the test that best measures the variable of interest, i.e. in targeting screening of back related health, rehabilitation or improving ergonomics.

Back lifting and extension strength and endurance tests are commonly used methods for testing back function in epidemiological research into back diseases, as well as in assessment of work ability and rehabilitation. Strength tests among measures of mobility and fitness have been used to measure back function, risk factors, specific treatment outcomes, disability and improved the back health of both low back pain (LBP) patients and healthy controls (Biering-Sorensen 1984, Mayer et al. 1985, Kankaanpää et al. 1999, Keller et al. 1999, Käser et al. 2001).

Some new devices are now acknowledged to help in the evaluation of back function (Taimela et al. 1998, Mannion et al. 1999, Larivièré et al. 2001). In general, the expectation has been that the new systems would provide greater precision and accuracy in the assessment of back function. However, results from these new devices as with the older systems often are conflicting in terms of their ability to predict back function (Battié et al. 1989, Gibbons et al. 1997b, Kankaanpää et al. 1998, Mannion et al. 1999, Keller et al. 1999, Larivièré et al. 2001, Larivièré et al. 2003). Subjective qualities, such as motivation and current pain (Mannion & Dolan 1994, Jörgensen 1997, Latimer et al. 1999) which can influence back function have received increasing attention when other determinants failed to demonstrate predictability.

The importance of understanding what the various back function tests truly measure is emphasized by high financial burden that society has to bear through the costs of rehabilitation. In Finland, the mean costs of medical treatment for individuals undergoing rehabilitation for musculoskeletal disorders were approximately 300 € for men and 400 € for women in 1999 (Kehusmaa & Mäki 2002). The overall cost of rehabilitation attributable to musculoskeletal disorders was over 15 million € in 2003 (Työeläkekuntoutus vuonna 2003).

The main objective of this doctoral thesis was to determine the reliability of the measures of back function related factors. One special focus was the possibility to detect changes in paraspinal muscles associated with back function test results, from magnetic resonance images (MRI). In addition, the relative effects of heredity and other constitutional and behavioral factors on isokinetic lifting force and work, psychophysical lifting strength and isometric back extension endurance by comparing monozygotic (MZ) and dizygotic (DZ) twins were investigated.

2 REVIEW OF THE LITERATURE

2.1 Overview of back function tests

The different back function tests of force, endurance, mobility and fatigue have been studied for how well they detect associations of back function and LBP (Marras et al. 2001a), e.g. for monitoring the effects of intervention or rehabilitation (Lindström et al. 1992, Mannion et al. 2001b), pre-employment (Jackson 1994) or return to work physical evaluations (Lemstra et al. 2004). There has also been some interest in evaluating how LBP can influence spinal loading during different tasks, such as lifting (Marras et al. 2001a).

A European survey identified the range of motion as being the most common measure of LBP related disability (Haigh et al. 2001). However, a review of reproducibility studies of low back function measures showed with respect to the trunk mobility measures that only the modified Schober test for forward flexion and finger-floor test for side bending were reliable measures whereas the reliability of trunk extension and rotation measures still awaited confirmation (Essendrop et al. 2002). Due to the problems of reproducibility of strength and endurance measures, it was recommended that upright standing isometric flexion and extension, dynamic strength assessed with different dynamometers, and trunk extension and flexion endurance tests should only be used for group-level studies (Essendrop et al. 2002). Thus, no consensus exists on which tests are reliable for use in screening of low back status.

There are no guidelines indicating which back function test is most applicable for assessing back function. It seems that several tests can either separately or together reflect a change in back function. For instance, Lindström et al. (1992) showed that rehabilitation of 51 LBP patients increased trunk mobility as assessed by modified Schober, lumbar range of motion, side bending, rotation, abdominal and back muscle endurance time and dynamic lifting capacity. A study of predictive value for future LBP showed that for healthy individuals (n = 307) and workers with previous LBP (n = 123) mobility as evaluated by modified Schober, finger-floor test for side bending, standing balance and isokinetic extension force would predict LBP (Takala & Viikari-

Juntura 2001). In addition, one study demonstrated that a combination of several straightforward sagittal-plane mobility tests (sock, pick-up, roll-up, finger-floor and lift tests) was more sensitive in detecting changes in back performance than any of the tests separately as examined in 157 subjects with LBP (Strand et al. 2002). In contrast, da Silva et al. (2005) comparing the back muscle fatigue in the upright position test, semicrouched lifting test and isometric back extension endurance test was not able to find any discriminative ability of these tests for LBP although differences between the tests in assessing fatigue were found.

2.2 Predictive value of the back function strength and endurance tests

The predictive value of the back function tests has been the focus of several studies and reviews over the years. But still today, no consensus exists (Pope 1989, Mooney & Andersson 1994, Takala & Viikari-Juntura 2000). Most of the interest has focused on the ability to predict future LBP. The early work of Biering-Sorensen (1984) showed that isometric back extension endurance might have prognostic value ($p = 0.03$) for first-time occurrence of LBP. Subsequently, the predictive value of first-time LBP by isometric back extension endurance test has been both supported (Alaranta et al. 1995, Moreau et al. 2001) and denied (Gibbons et al. 1997b, Stewart et al. 2003, da Silva Jr et al. 2005) in healthy subjects. In addition, the loss of isometric back extension endurance for chronicity of LBP has been found to have indicative value by Hultman et al. (1993). It has also been shown that the isometric back extension endurance test discriminates between subjects with and without LBP (Nicolaisen & Jörgensen 1985, Holmström et al. 1992, Parkkola et al. 1992, Simmonds et al. 1998, Latimer et al. 1999).

At present, isokinetic and isometric lifting strength tests have not been shown to possess the ability to discriminate LBP patients ($n = 58$) from healthy volunteers ($n = 21$) (Mandell et al. 1993). Many groups, e.g. Battié et al. (1989) who evaluated 495 healthy subjects of 21-67 years of age, Troup et al. (1987) with 2891 healthy subjects and Adams et al. (1999) with 403 healthy volunteers of 18-43 years of age could not find any predictive value for future LBP by measuring isometric lifting strength. Also the recent results of da Silva Jr et al. (2005) who compared 15 healthy controls with 13 nonspecific chronic LBP patients of 25-55 years could not find discriminative ability for LBP as assessed by the semicrouched lifting test.

In addition to endurance and lifting tests, trunk extension tests have also been evaluated but these have also yielded conflicting results. The isometric trunk extension/flexion strength ratio of 41 LBP patients and 7 healthy subjects has been shown to be associated with the Oswestry disability score ($r = -0.32$, Triano & Schultz 1987), and isokinetic trunk extension/flexion strength ratio measured in 67 healthy men predicted LBP (p = 0.001, Lee et al. 1999). Kujala et al. (1996) found no association between isometric and dynamic trunk strength and LBP in their five year follow-up study of a total of 456 25-55-year-old healthy volunteers. The results of da Silva Jr et al. (2005) with isometric extension strength test in the upright position also failed to discriminate LBP. However, isokinetic trunk extension strength has been shown to discriminate nine healthy subjects from ten subjects with LBP (Grabiner & Jeziorowski 1992) and poor dynamic trunk extension strength was used to predict LBP related work disability in 535 healthy volunteers of 30-64 years of age (Rissanen et al. 2002).

2.3 Determinants of back function tests

Although a variety of back function tests of trunk force, isometric back extension endurance and lifting performance are commonly used for similar purposes, the results of these tests are poorly correlated mutually, indicating that they are measuring different aspects of function with different underlying determinants (Smith et al. 1985, Troup et al. 1987, Mayer et al. 1988, Hazard et al. 1993, Mandell et al. 1993, Latikka et al. 1995, Mayer et al. 1995, Gibbons et al. 1997b, Hupli et al. 1997). Several constitutional factors are known to exhibit some association with back function test results (Figure 1), such as age (Battié et al. 1989, Jerome et al. 1991, Alaranta et al. 1995, Gibbons et al. 1997b, Kankaanpää et al. 1998) and different anthropometric factors (Battié et al. 1989, Jerome et al. 1991, Estlander et al. 1994, Malchaire & Masset 1995, Gibbons et al. 1997b, Kankaanpää et al. 1998, Mannion et al. 1999, Gross et al. 2000). Also lifestyle factors and particularly behavioral factors play a role in back function, such as motivation (Matheson et al. 1992, Estlander et al. 1994, Lackner & Carosella 1999), the presence of back pain (Battié et al. 1989, Holmström et al. 1992, Estlander et al. 1994, Rissanen et al. 1994, Burdorf et al. 1995, Alaranta et al. 1995, Gibbons et al. 1997b, Keller et al. 1999, Lackner & Carosella 1999), health (Malchaire & Masset 1995, Gibbons et al. 1997b, Malmberg et al. 2002), profession and education (Burdorf et al. 1995, Alaranta et al. 1995) and physical activity (Holmström et al. 1992, Malchaire & Masset 1995, Gibbons et al. 1997b). In addition, factors related to the test situation may affect the results obtained in a back function test, for instance whether or not there are rest periods between lifts and also the lifting technique used (Noe et al. 1992, Hazard et al. 1993). The extent of the influence of these factors depends on the back function test and the tested subjects (Figure 1).

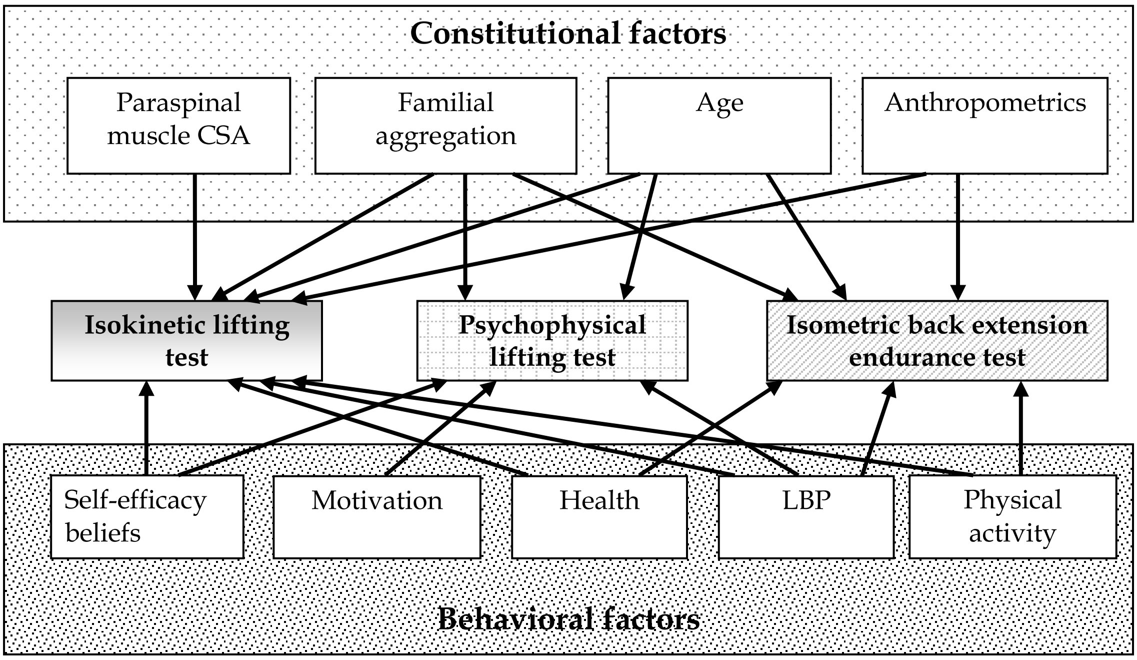

FIGURE 1 Constitutional and behavioral determinants of the three back function tests (Arrows indicate known associations between different factors and back function tests)

The strength of the association between the different factors and the results obtained in the back function tests has varied from study to study. There may be several reasons for the variation i.e. type of the test and the role of the modifying factor in the study setting. For example, pain has been investigated in studies where LBP patients seemed to perform poorly in isometric extension strength and endurance compared to those without LBP (Holmström et al. 1992), but also subjective control of pain in dynamic lifting (Lackner & Carosella 1999) can affect performance. Another study investigated whether pain had any effect on exertion in isokinetic extension force (Keller et al. 1999); whereas others have been more interested in assessing whether future LBP could be predicted by isometric back extension endurance test performance (Alaranta et al. 1995). In addition, the selected measure to predict outcome can affect the association. For example, several anthropometric measures have been considered in relation to back function such as BMI, body weight, height, and body fat (Battié et al. 1989, Gibbons et al. 1997b, Mannion et al. 1999, Gross et al. 2000) and these have led to a wide range of correlation coefficients for the association from -0.04 to 0.68. The association between different factors and back function can also be influenced by the fact that certain factors may exhibit mutual associations e.g. anthropometrics and physical activity (Kyle et al. 2001, Lahti-Koski et al. 2002). Some factors may include a genetic component which means that some of the impact of an association can be attributable to a genetic effect. For example, physical activity (Beunen & Thomis 1999, Lauderdale et al. 1997, Maia et al. 2002) and anthropometric measures (Bouchard 1991, Schousboe et al. 2004) are mainly genetically determined. There is also one study showing that physical activity shares a genetic component with percent body fat (Simonen et al. 2004) suggesting that the influences of physical activity and anthropometrics might be partially accounted for by common genetic components.

2.3.1 Isokinetic lifting performance

The isokinetic back lift is based on a lift movement performed at a concentric, constant speed. The dynamic lifting event resembles biomechanically real-world lifting tasks when the extremities are involved. Currently there are several manufacturers which produce different measurement devices for isokinetic testing, both for lifting or testing trunk extension and flexion, and either in the upright or seated position (Grabiner et al. 1990, Dvir 1991, Hazard et al. 1993, Estlander et al. 1994, Rissanen et al. 1994, Gibbons et al. 1997b, Hupli et al. 1997, Takala & Viikari-Juntura 2000, Keller et al. 2001).

A positive correlation of muscle CSA and muscle force is a basic principle of muscle physiology (Bruce et al. 1997, Keller et al. 1999), yet the results of studies investigating the relationship between isokinetic lifting performance and paraspinal muscle CSA have yielded conflicting results (Table 1). Isokinetic lifting performance has been associated with paraspinal muscle CSA in middle-aged healthy volunteers and LBP patients of both genders (Mayer et al. 1989, Hultman et al. 1993, Gibbons et al. 1997a, Keller et al. 1999). Also isoinertial trunk extension force of healthy men was weakly associated with paraspinal muscle CSA (Räty et al. 1999). However, in some studies with LBP patients, isokinetic trunk extension force and the CSA of various trunk muscles exhibited no association (Storheim et al. 2003, Keller et al. 2004). One explanation for these inconsistencies might be that performance on the isokinetic back function performance has other more influential determinants than muscle CSA (Table 1).

Familial aggregation has been a more influential determinant than the muscle CSA in isokinetic back function tests explaining 56% of variance in isokinetic lifting force (Gibbons et al. 1997b). In addition, isokinetic back function appears to be influenced by attitudes and beliefs about self-efficacy and self-assessed health. Self-efficacy beliefs have been found to be positively correlated with isokinetic lifting (Hazard et al.1993, Keller et al. 1999, Lackner & Carosella 1999) and isokinetic trunk extension force in standing (Estlander et al. 1994). Also self-assessed health has been found to correlate with isokinetic lifting force (Gibbons et al. 1997b). Age has been reported to affect performance in isokinetic lifting and isokinetic trunk extension (while standing) tests in samples of 21-54 years old (Smith et al. 1985, Jerome et al. 1991, Estlander et al. 1994) (see also Table 1). However, the influence of age i.e. from young through middle adulthood among 25-50 years old on isokinetic lifting performance is less clear (Mostardi et al. 1992).

Anthropometric factors also appear to be of some importance, though there are several studies showing a moderate association with isometric back extension strength and maximal lifting capacity among patients and healthy volunteers (Malchaire & Masset 1995, Mannion et al. 1999, Gross et al. 2000, Wang et al. 2005), but there is one study where no correlation was found

(Larivière et al. 2003). In a study of male MZ twins, co-twins who were taller than their twin brothers also had higher isokinetic lifting force (Gibbons et al. 1997b). In line with this, those LBP patients who were taller had better isokinetic trunk extension force in standing (Estlander et al. 1994). With respect to the other anthropometric measures, lean body mass has been found to explain a relatively large proportion of the variance in maximal back efforts, 41% by Gibbons et al. (1997b) and have a strong association, r = 0.67 according to Mannion et al. (1999). However, after including familial aggregation into the model, the variance explained by lean body mass dropped to 8% (Gibbons et al. 1997b). This was to be expected from the earlier findings that anthropometric measures contain a significant genetic component (Bouchard 1991, Coady et al. 2002, Schousboe et al. 2004) that may account for some of the impact of these factors.

TABLE 1 Some known determinants for isokinetic lifting performance (na = exclusion criteria from the study were not reported)

Lead author, year	Determinants	Subjects, n	age	Exclusions	Results
Gibbons 1997a	Paraspinal muscle CSA	Population based sample of male twins, n = 110	35-67	Pain, colds, untreated high blood pressure, prior myocardial infarctions or other physical condition affecting muscle performance	Correlations between different paraspinal muscles were r = 0.46-0.63
Gibbons 1997b	Age	Population based sample of male twins, n = 130	35-67	Pain, colds, and other physical condition affecting muscle performance	Younger age was associated with better performance in isokinetic lifting, r = -0.38
	Body weight				Those who were heavier had better performance in isokinetic lifting, r = 0.59
Hultman 1993	Erector spinae CSA and density	36 healthy men, 91 intermitted LBP, 21 Chronic LBP	45-55	na	Correlation between healthy males erector spinae CSA and isokinetic trunk force was r = 0.61
Keller 1999	Erector spinae and multifidus CSA and density	Chronic LBP patients, 50 men, 70 women	21-70	Failure of filling questionnaires, not able to perform isokinetic force test	Muscle area was significant predictor for isokinetic back muscle force after controlling for other factors ($p < 0.001$)
	Age				No effect
Latikka 1995	Age	Population based sample of men twins, n = 100	35-67	Pain, colds, untreated high blood pressure, prior myocardial infarctions or other physical condition affecting muscle performance	Younger age was associated with better performance in isokinetic lifting, r = -0.41
Mayer 1989	Paraspinal muscle CSA and density	Spinal surgery patients, 35 men, 11 women and normal subjects, 11 men, 8 women	25-57	na	Those with better muscle density in paraspinal CT did better in isokinetic force test
Mostardi 1992	Age	171 women	21-61	Pregnancy, pain at the time of testing, back surgery or back-related injury 6 months before testing	Older age (> 30 years) was associated with less isokinetic lifting force, r = -0.35--0.48
	Body weight				Isokinetic force and body weight had no significant correlation, but those who were lighter had better force indicated with force/body weight

Intensity and frequency of LBP history have been shown to have an influence on dynamic and isokinetic back function test performance in the majority of studies of non-patient samples (Leino et al. 1987, Malchaire & Masset 1995, Latimer et al. 1999), but not in all studies (Battié et al. 1989, Mostardi et al. 1992, Gibbons et al. 1997b). In chronic LBP patients, pain severity and other aspects of LBP have been associated with isokinetic lifting and trunk extension performance both in sitting and standing positions (Mayer et al. 1989, Grabiner & Jeziorowski 1992, Hultman et al. 1993, Mandell et al. 1993, Estlander et al. 1994, Rissanen et al. 1994, Hupli et al. 1996, Grönblad et al. 1997, Keller et al. 1999, Rantanen 2001). The model of fear-avoidance of pain indicates that the avoidance of physical activity (as is needed in lifting effort) due to prior experiences of back pain can affect back function or force (Lethem et al. 1983, Slade et al. 1983, Crombez et al. 1998).

Few works have studied the effects of physical activity other than therapeutic exercise (Storheim et al. 2003) on isokinetic back function test performance, which may be explained, in part, that most studies have involved LBP patient samples, and there may also be variations in definitions of physical activity and difficulties with its accurate measurement. Currently, there are two studies of physical activity and isokinetic back performance where no difference has been found in isokinetic lifting performance between active and inactive subjects with or without back problems (Gibbons et al. 1997b), although in healthy workers, leisure-time activities and dynamic back performance were statistically significantly associated (Malchaire & Masset 1995).

The repeatability of isokinetic lifting has been determined in a study of healthy working age adults, and intra-test repeatability of peak force and total work yielded an Intraclass Correlation Coefficient (ICC) of 0.97 (Latikka et al. 1995) and an inter-test repeatability of ICC of 0.87-0.96 (Hazard et al. 1993, Latikka et al. 1995).

2.3.2 Psychophysical lifting capacity

In a psychophysical lifting test, subjects are advised to use the force they can comfortably sustain for five seconds as near to maximum as possible at knee level. The psychophysical lifting test requires the subject’s perception of his or her lifting capacity. As the name “psychophysical” implies, the psychophysical lifting test would seem to be the best tool for estimating behavioral factors often related to back pain or possible impairment (Foreman et al. 1984, Troup et al. 1987, Troup 1991, Holmström et al. 1992, Burdorf et al. 1995, Malchaire & Masset 1995, Gibbons et al. 1997b). In this study, psychophysical lifting test was defined to include only the psychophysical test at knee level excluding other psychophysical tests of lifting such as free lifting assessed with psychophysical approach (Han et al. 2005) and lifting equation of National Institute for Occupational Safety and Health (Elfeituri & Taboun 2002). Psychophysical lifting test at knee level has not received wide popularity as a part of back function test battery. In general, psychophysical lifting tests have been mainly used for ergonomic evaluations (Troup 1991, Jörgensen et al. 1999) or outcome measures for therapeutic interventions (Troup 1991).

So far, determinants for psychophysical lifting test at knee level have been explored in a few studies (Troup et al. 1987, Latikka et al. 1995, Gibbons et al. 1997b). However, some determinants of psychophysical lifting capacity can be derived from those determinants related to the submaximal isometric lifting test (Battié et al. 1989, Holmström et al. 1992, Parkkola et al. 1992, Malchaire & Masset 1995) due to the submaximal level of effort in psychophysical lifting performance. There are several determinants of psychophysical lifting capacity, but familial aggregation may be the most important, explaining 32% of variance in MZ male twins (Gibbons et al. 1997b). Paraspinal muscle CSA of working age subjects was not associated with psychophysical lifting (Gibbons et al. 1997b), and age affected only marginally or not at all on the psychophysical lifting capacity of working age subjects (Latikka et al. 1995, Gibbons et al. 1997b). The earlier findings of Troup et al. (1987) also showed that the prevalence of LBP may affect the capability to achieve the age-related level of strength in psychophysical lifting.

The intensity and frequency of LBP history have been shown to influence psychophysical and isometric back lifting performance in part of the studies of non-patient samples (Troup et al. 1987, Malchaire & Masset 1995), but not in all studies (Battié et al. 1989, Gibbons et al. 1997b). However, apparently LBP patient samples have not been studied with psychophysical lifting test for the pain effect. With respect to behavioral factors, self-efficacy beliefs have been found to be positively correlated with isometric lifting force (Hazard et al. 1993, Malchaire & Masset 1995), but self-assessed health had no correlation with psychophysical lifting (Gibbons et al. 1997b). Thus, perceived work load rated by the subjects for the physical exertion was highly associated with psychophysical lifting capacity (Troup et al. 1987).

The psychophysical lifting test has been shown to be reliable (Troup 1991). Inter-tester reliability among healthy working-age subjects yielded high correlation coefficients ranging from 0.87 to 0.96 (Foreman et al. 1984, Alaranta et al. 1994).

2.3.3 Isometric back extension endurance test

The isometric back extension endurance test measures isometric endurance by timing how long a subject can keep the unsupported upper body horizontal while lying prone with the hands held behind the neck, across the chest or on the sides of the body (Moreau et al. 2001). A series of studies by Gibbons et al. (1997ab) revealed that isometric back extension endurance was affected by familial aggregation (heredity and shared life-time exposures and experiences) explaining 15% of the variance in isometric back extension endurance in 35-67 -year-old MZ male twins (Gibbons et al. 1997b), but age had either little effect or no effect at all (Gibbons et al. 1997a). In contrast to findings of no effect of age among 35-67-year-old individuals (Gibbons et al. 1997a), lower isometric back extension holding time has been found in older adults as compared to those of younger age for different samples of 26-67 years of age (Latikka et al. 1995, Kankaanpää et al. 1998)(Table 2). Those healthy subjects of both genders with a high percentage of body fat demonstrated shorter isometric back extension holding time (Kankaanpää et al. 1998) supporting the results of Gibbons and colleagues (1997b). However, Gibbons et al. (1997a) failed to show an association with isometric back extension endurance and paraspinal muscle cross-sectional area (CSA) in agreement with Hultman et al. (1993).

With respect to the behavioral factors which can affect isometric back extension endurance, different aspects of LBP history have been shown to influence the isometric back extension holding time in the majority of studies of non-patient samples (Bigos et al. 1992, Holmström et al. 1992, Taimela et al. 1998, Latimer et al. 1999) and LBP patients (Hultman et al. 1993, Lindström et al. 1995), but not in all studies (Jörgensen & Nicolaisen 1987, Gibbons et al. 1997b). Differences in the definition of back pain history and current LBP status and severity of the episode among healthy subjects (Gibbons et al. 1997b) may have explained why no effect was detected. This negative finding in healthy subjects may be due to two reasons; either the episode of LBP was not severe or not long enough to affect test performance. Thus, in studies of chronic LBP patients, LBP has been associated with back endurance (Jörgensen & Nicolaisen 1987, Hultman et al. 1993, Lindström et al. 1995, Grönblad et al. 1997, Suni et al. 1998, Taimela et al. 1998) (Table 2). With respect to health, self-assessed health has exhibited only a weak association with isometric back extension endurance (Gibbons et al. 1997b, Suni et al. 1998). Smoking and obesity have not shown any association (Moffroid et al. 1994), but greater leisure-time physical activity did correlate with isometric back extension endurance test performance (Holmström et al. 1992, Moffroid et al. 1994, Taimela et al. 1998).

According to one literature review, the isometric back extension endurance test is valid, reliable, and useful in clinical settings for tracking changes in isometric back extension endurance (Moreau et al. 2001). However, a later review by Essendrop et al. (2002) and the results of da Silva Jr et al. (2005) indicated that its sensitivity for detecting changes in back function performance by isometric back extension endurance test was less impressive than claimed by Moreau et al. (2001). Essendrop et al. concluded that isometric back extension endurance test should be used on groups due to the lack of information of reliability of isometric back extension endurance. The inter-test repeatability for isometric back extension endurance test has varied from ICC = 0.59 to 0.83 (Troup et al. 1987, Alaranta et al. 1994, Moreland et al. 1997, Simmonds et al. 1998, Latimer et al. 1999, Keller et al. 2001) and correlation coefficients from r = 0.20 to 0.91 (Jörgensen & Nicolaisen 1987, Hyytiäinen et al. 1991, Holmström et al. 1992, Mayer et al. 1995) in earlier studies of healthy subjects. For subjects with LBP, the reliability of isometric back extension endurance test has been for inter-test of current LBP ICC = 0.88 and for previous LBP ICC = 0.77 (Latimer et al. 1999), and for intra-test of chronic LBP ICC = 0.80-0.93 (Moffroid et al. 1994, Keller et al. 2001).

TABLE 2 Some known determinants for isometric back extension endurance (na = exclusion criteria from the study were not reported)

Lead author, year	Determinants	Subjects, n	Age	Exclusions	Results
Gibbons 1997b	Age	Population based sample of 130 male twins	35-67	Pain, colds, and other physical condition affecting muscle performance	Younger age was associated with better performance in isokinetic lifting, r = -0.21
	Body fat				r = -0.41
	Health better than others of the same age				r = 0.25
Grönblad 1997	Pain disability index	55 patients; 28 men, 27 women	34-51	Other major diseases causing disability, vertebral factures, a disc herniation requiring operative treatment, a diagnosed psychiatric disorder requiring medication, a diagnosed underlying disorder causing LBP and pregnancy	r = -0.24
Holmström 1992	LBP	All men: 42 healthy subjects, 75 uncertain LBP cases, 86 current or previous LBP	34-54	na	Isometric back endurance time was shorter in those with current/previous LBP than other groups, $p < 0.01$
Hultman 1993	LBP	36 healthy men, 91 intermitted LBP, 21 chronic LBP	45-55	na	Isometric back endurance time was shorter in those with LBP, $p < 0.001$
Jorgensen 1987	LBP	53 healthy men	27-60	na	Isometric back endurance time was shorter in those with LBP, exact significance not given
Latimer 1999	LBP	23 with current non-specific LBP, 20 with previous non-specific LBP, 20 healthy subjects	20-52	Diagnosed cardiovascular disease or neurologic disease, pain was caused by a specific disease process such as infection, tumor, or injury to a specific anatomic structure such as a vertebral body fracture	Isometric back endurance time was shorter in those with LBP, $p < 0.05$
Moffroid 1994	Physical activity	32 chronic LBP patients; 14 men, 18 women	20-60	na	Isometric back endurance time was shorter in physically inactive subjects, $p < 0.03$

2.4 Magnetic resonance imaging of lumbar paraspinal muscles

MRI is based on the interaction between hydrogen nuclei (protons) in the tissues and the magnetic fields generated and monitored by the MRI instrumentation (Ross 2003). The signal intensity of each pixel from a MR image signal intensity threshold can be evaluated by the signal intensity value using image analysis software (Ranson et al. 2005). The muscle composition in MR images can be separated by the signal intensity of pixels of different tissues within the region of interest. The variation of water content on tissues from MR images can separate muscle fibers with a high water content (low intensity pixels), from ligaments and fat tissue which have a low water content (high intensity pixels). Studies of paraspinal muscles by MRI have shown the advantages of the method i.e. non-invasive, subject safe, and ability to separate clearly the tissues of interest. Thus MRI has been used to measure muscle size (CSA), composition (quality) and pathology (Tracy et al. 1989, Parkkola & Kormano 1992, Parkkola et al. 1993, Wood et al 1996, Gibbons et al. 1998, Dangaria & Naesh 1998, Kader et al. 2000, Käser et al. 2001).

Healthy muscles and those with muscle atrophy look very different in MR images (Kader et al. 2000). Studies into muscle composition would be of interest, but only a few studies have investigated quantitatively the MR imaged muscle composition (Parkkola & Kormano 1992, Flicker et al. 1993, Gibbons et al. 1997a, Ranson et al. 2005). Criteria for paraspinal muscle atrophy in computed tomography (CT) or MR images can be either decreased muscle CSA or fatty deposits (increased fat/muscle fiber ratio or actual fatty replacement of fibers) (Mayer et al. 1989, Parkkola & Kormano 1992, McLoughlin et al. 1994, Ranson et al. 2005). Atrophy of paraspinal muscle fibers at L3-level (Mayer et al. 1989), L3-L4 (Storheim et al. 2003) and L4-L5 level (Parkkola et al. 1993, Storheim et al. 2003) has been shown to be related to disuse and/or degenerative findings. Also nerve ramus damage at the affected level might be a partial reason for the CSA decrease. For example, Sihvonen et al. (1997) used electromyography to reveal that patients with ventral root impingement have nerve damage in the area of innervating paraspinal muscles. Clear evidence exists for wasting of paraspinal muscles due to LBP or low back disability (Cooper et al. 1992a, Alaranta et al. 1993, Parkkola et al. 1993, Mayer et al. 1995, Danneels et al. 2000, Barker et al. 2004). There are several reasons why muscle quality can deteriorate e.g. decrease in muscle fiber size secondary to disuse or deconditioning and/or muscular changes from muscle stripping. This is because inactivity may lead to a decrease in force without affecting muscle CSA. One possible explanation for the unchanged CSA is that when muscle fibers decrease, fat is deposited in place of the muscles, and thus the connective tissue remains the same and muscle CSA does not change (McLoughlin et al. 1994). The initial decrease in force may be caused by changes in the neural activation component of the muscle during inactivity, not by changes of muscle CSA. Thus, morphological factors of paraspinal muscles did not predicted back pain during one-year follow-up, when CSA was determined from muscles of the right side and at the level of L4-L5 (Gibbons et al. 1997c).

2.4.1 Reproducibility of the paraspinal muscle CSA and composition measurements

Many studies of lumbar discs have been carried out with MRI showing moderate reliability of assessments, where intra-rater reproducibility for various parameters has been ICC = 0.54-0.98 and inter-rater ICC = 0.21-0.93 (Videman et al. 1994, Battié et al. 1995, Videman et al. 1998) and inter-rater relative percentage of difference –11.5-3.7% (Malko et al. 1999). The reproducibility of paraspinal muscle size and composition measurements by MRI have been found to be good, ICC = 0.89-0.99 (Table 2). However, most often the repeatability of paraspinal muscle CSAs measured by MRI has been reported without stating the specific criteria or acquisition methods used (Tracy et al. 1989, Dangaria & Naesh 1998, Gibbons et al. 1998, Barker et al. 2004) (Table 3). In addition, some studies reported no estimates of repeatability of CSA analysis (Parkkola & Kormano 1992, Wood et al. 1996, Kader et al. 2000, Käser et al. 2001). The repeatability of muscle composition measurements has been calculated based on graded estimates of paraspinal muscle degeneration where inter-rater agreement was K = 0.85 (Kader et al. 2000). With computed tomography (CT) imaged paraspinal muscles, the inter-rater reliability coefficients of CSAs and histographic method for fat were 0.81-0.92 (Danneels et al. 2000). The repeatability of quantitative muscle composition measurements of MR images has been rarely studied; in the few published studies the repeatability of signal intensity of the muscles was ICC < 0.99 for 6 and 20 healthy subjects (Gibbons et al. 1997a, Ranson et al. 2005).

2.4.2 Determinants of paraspinal muscles cross-sectional area

Paraspinal muscle CSA has been found to decrease with age (Troup et al. 1986, Parkkola & Kormano 1992, Mannion et al. 2000). In a cross-sectional study of working aged men, age was weakly associated with paraspinal muscle CSA by 3-9% per 10 additional years of age (Gibbons et al. 1998), but familial aggregation had a major influence on variance of paraspinal muscle CSA, 66-73%. The influence of physical load at work and leisure-time, history of neck and back pain, overall health and anthropometrics (height, body weight and body fat percentage) contributed only marginally to paraspinal muscle CSA when familial aggregation was accounted for (Gibbons et al. 1998). Most studies have not shown any association between paraspinal muscle CSA and body weight (Parkkola & Kormano 1992, McLoughlin et al. 1994, Wood et al. 1996), though there are two studies reporting a positive association (Reid et al. 1987, Cooper et al. 1992b). An association has been shown between CSA of the erector spinae and body fat percent (Gibbons et al. 1998) and paraspinal muscles CSAs and lean body mass (Mannion et al. 2000). However, estimates of paraspinal muscle fat deposits did not correlate with overweight (Parkkola & Kormano

1992). There were no differences between lean and obese men in paraspinal muscle CSA and paraspinal muscles CSA in middle-aged healthy men which could not been explained by the anthropometric variables (Wood et al. 1996).

2.4.3 The association of paraspinal muscles cross-sectional area with back function

Paraspinal muscle CSA has been claimed to be an objective measure for back function (Bruce et al. 1997, Keller et al.1999) and it has been suggested that muscle CSA needs to be known if one wishes to evaluate factors affecting muscle force change (i.e. due to aging, physical activity, work load). Peltonen et al. (1998) have conducted a unique study to show that the time spent in physical training has a positive correlation with paraspinal muscle CSA, and back muscle force and endurance. However, the results of Peltonen & colleagues were based on adolescent girls where natural growth and development have a known role. In adults, the results of the association between paraspinal muscle CSAs and exercises of low back (including both strength and endurance training) (Parkkola et al. 1992, Mooney et al. 1997, Danneels et al. 2001, Keller et al. 2004), physical rehabilitation consisting of treatments and active therapies (Käser et al. 2001, Mannion et al. 2001a, Storheim et al. 2003) or pain (Savage et al. 1991, Hultman et al. 1993, Mannion et al. 2000) have either been absent or controversial. The lack of consistency in the relationship between CSA and back function has emphasized the importance of measuring the quality (composition) of the paraspinal muscles in addition to their size. Studies of the association between back function test performance and paraspinal muscle composition measures have shown that paraspinal muscle composition was moderately to weakly related to isokinetic trunk extension force ($r = 0.61$, Hultman et al. 1993, $R^2 = 4\%$, Keller et al. 1999). Isokinetic lifting performance and psychophysical lifting capacity (Gibbons et al. 1997a) and isometric back extension endurance time (Hultman et al. 1993, Gibbons et al. 1997a) have not been shown to correlate with muscle quality parameters.

The correlation of back muscle force and paraspinal muscle CSA may also be affected by the selected level or location of CSA measures. Theoretically, the CSA at the thickest site of a muscle should provide the most repeatable CSA measurement and the most accurate correlation with force. Most studies of paraspinal muscle CSA both in healthy volunteers and in LBP patients of both genders have used only one level, either L3-L4 (Gibbons et al. 1997a, Räty et al. 1999, Käser et al. 2001) or L4-L5 (Reid et al. 1987, Tracy et al. 1989, Parkkola et al. 1992, McGill et al. 1993, Wood et al. 1996, Keller et al. 1999). Recently, the lumbar spine level L3-L4 has been suggested to have the highest association between paraspinal muscle CSA and isometric back extensor force (Käser et al. 2001). However, muscle CSA can exhibit large changes over the length of a single or a few vertebrae (McGill et al. 1993) and therefore studying CSAs at several levels has been recommended (Alaranta et al. 1993).

In addition, the side of the spine where the CSA measures are taken may have an influence on the relationship between force and muscle size. Hand dominance, postures at work, physical activity, LBP and other factors can affect the muscles of the right and left sides of spine differently. Thus, most studies of muscle CSAs have used the sum of the right and left side (Reid & Costigan 1987, Parkkola et al. 1992, McGill et al. 1993, Keller et al. 1999, Räty et al. 1999). It seems that very few have studied the difference between right and left side CSAs. Earlier, for normal subjects, Millerchip et al. (1988) found equal size of right and left side. Also in one study of chronic LBP patients using CT, Cooper et al. (1992a) found no clear differences between left and right CSAs and chose to use the measurements from one side only. Differences have been found by Dangaria & Naesh (1998) in psoas major CSA without favour to either side among patients and healthy controls. Later, Käser et al. (2001) found larger erector spinae CSA's on the left side than the right among chronic LBP patients and Marras et al. (2001b) found a larger right side latissimus dorsi CSA, but not psoas major in their whole spine length study of healthy volunteers. Recently, Barker et al. (2004) investigated patients with unilateral back pain, and reported that CSA was larger on the side without symptoms, suggesting that for LBP patients the side exhibiting the symptoms will probably affect the side difference of CSAs.

TABLE 3 Reproducibility of paraspinal muscle CSA estimates obtained by MRI

Author, year	**N**	**Paraspinal muscles**	**Method**	**Variation**	**Repeatability**
Tracy et al. 1989	na, patients	Right erector spinae, quadratus lumborum, psoas major, rectus abdominis, latissimus dorsi, obliques muscles at L2-L3, L3-L4, L4-L5 and L5-S1 levels	0.15 T MRI device, proton density images	Inter-rater	0.5-5 cm^3
Gibbons et al. 1998	18, volunteers	Bilateral erector mass, psoas major and quadratus lumborum muscles at L3-L4 level	1.5 T MRI device, T2 weighted images	Intra-rater	ICC > 0.94
Dangaria & Naesh 1998	na, patients and volunteers	Bilateral psoas major muscle at L3-L4, L4-L5 and L5-S1 disc levels	1.0 T MRI device	Inter-rater	± 0.05%
Peltonen et al. 1998	7, adolescent girls	Bilateral psoas major muscle and erector mass at L4-L5 level	0.1 T MRI device, proton density images	Inter-rater	ICC = 0.91-0.93
Räty et al. 1999	20, former elite male athletes	Bilateral erector mass, psoas major and quadratus lumborum muscles at L3-L4 level	1.5 T MRI device, T2 weighted images	Intra-rater	ICC = 0.91-0.99
Marras et al. 2001b	15, female volunteers	Bilateral erector mass, latissimus dorsi, internal obliques, external obliques, rectus abdominis, psoas major and quadratus lumborum at levels T8-S1	1.5 T MRI device, proton density images	Intra-rater	Coefficient of variation < 9%
Barker et al. 2004	10, patients	Bilateral psoas and multifidus at levels L2-S1	1.5 T MRI device	Intra-rater	ICC = 0.89-0.92

na = N for repeatability estimates not reported

3 OBJECTIVES

The main objective of this doctoral thesis was to determine the reliability of commonly used methods to measure background factors of back function. Investigating the possibilities to detect changes in paraspinal muscles (which would be associated with back function test results) from MR images commonly available from patients with back disorders was one specific interest. In addition, the relative effects of heredity, other constitutional and behavioral factors on the three back function tests (isokinetic lifting performance, psychophysical lifting capacity and isometric back extension endurance) were investigated by comparing MZ and DZ twins.

The specific objects were to:

- Determine the reliability of lifetime exercise data obtained through a structured interview both for the most commonly performed mode of exercise, and for exercise data pertaining to the two most commonly performed exercise modes and the entire lifetime exercise history. (**I**)
- Investigate the intra-rater reliability and construct validity of quantitative and qualitative measurements of total muscle CSA and composition, using the digital data from routine lumbar spine MRIs. Also to investigate the correlations of the qualitative ratings of muscle composition (e.g., fat infiltration) with body fat percentage and isokinetic lifting performance and correlations of isokinetic lifting performances with total paraspinal muscle CSA and paraspinal muscle CSA after adjusting for measurements of muscle composition. (**II**)
- Investigate the relative roles and associations of physical activity and anthropometric parameters in back performance testing. Compare the associations between different physical activity parameters and anthropometric measures in isokinetic lifting performance, isometric back extension endurance and psychophysical lifting tests. (**III**)
- Determine the relative contributions of genetic, common (shared family) and unique constitutional and behavioral factors as determinants of isokinetic and psychophysical lifting capacity and isometric back extensor endurance test performances using a classic twin study. (**IV**)

- Investigate the reported reasons for ending the isometric back extension endurance test, and to determine if the reasons for test termination vary according to test performance. (**V**)

4 METHODS

4.1 Subjects

A total sample of 147 MZ and 153 DZ male twin pairs, 35 to 70 years of age (mean 49.9 years, SD = 7.7), was drawn from the Finnish Twin Cohort. The Finnish Twin Cohort was established by identifying all same-sexed twin pairs born before 1958 and alive in 1975 from the Central Population Register of Finland, which has data on all Finnish citizens and residents (see for details Kaprio et al. 1978, Kaprio & Koskenvuo 2002) making the sample population-based. Selection criteria were based solely on within-pair differences in occupational materials handling, sedentary work, exercise, driving history, or cigarette smoking (Battié et al. 1995). Additional pairs (n = 33 pairs) were selected to increase the sample size, and they were selected at random with the goal of enhancing the representativeness of the sample.

I: A sample of 150 men was selected from the 234 subjects who had participated in a study of the effects of common exposures on musculoskeletal aging or degeneration. Interviews were carried out during 1992-93 and were repeated in 1997. Exercise data were missing for one subject because he reported no matching modes of exercise in interviews 1992-93 and 1997.

II: A sample of 169 men was randomly selected from the total sample and data included axial MR images at L3-L4 lumbar spine level, isokinetic lifting performance and body fat percentage (body fat) by bioelectrical impedance. Subjects were not excluded based on any morbidity (except for the presence of metal parts in the body, which is a contraindication for MRI monitoring).

III: A sample of 210 men with data of lifetime interview, three back function tests and axial MRIs at L2-L3 through L4-L5 lumbar spine levels.

IV: Data were acquired for the total sample of 147 MZ and 153 DZ male twin pairs. Fifty-eight subjects were not tested because of acute or severe back pain, heart problems, hand impairment, or cancer metastases causing pain during performance (n=50) or malfunction of the testing device (n=8). For inclusion into the analyses, complete data were required for the three back function performance tests, isokinetic and psychophysical lifting capacity, and isometric back extension endurance, for both twins of a pair, leading to inclusion of 122 MZ and 131 DZ pairs.

V: The study subjects were the total sample of 600 male twins. Those who had poliomyelitis, heart malfunction (angina pectoris, cardiac arrhythmias, or other severe heart conditions), had consumed alcohol the night before, high blood pressure (either very high or repetitively high: systolic blood pressure over 140 mmHg or diastolic blood pressure over 90 mmHg), vertigo, paralysis, recent back surgery (within one year), cerebral palsy, tremor, demented behavior (no diagnosed dementia, but could not understand the instructions), or those who could not produce the starting position due to obesity or restricted shoulder range of motion, were excluded from isometric back extension endurance testing. Altogether 56 subjects (9%) were not tested due to the above mentioned reasons leaving 544 for inclusion in the study.

4.2 Interview (I, III, IV, V)

Information on lifetime work and exercise histories and other regularly performed activities involving physical loading and a detailed history of neck and back pain and other health problems were collected in a thorough, structured interview. Five trained interviewers carried out the interviews. The same person interviewed both siblings of a pair, and each interview took approximately 2.5 hours to complete.

4.2.1 Work history

Each subject discussed in detail every job held for at least 3 months since the age of 12 years to estimate the lifetime physical loading exposures experienced at work. The subject's profession, time spent driving and sitting on the job (hours per day), average weight lifted (in kilograms) and frequency of lifting (number of times per hour, per day, and per week), different working positions (minutes per hour), standing and walking during work (hours per day), weekly working hours, recalled trauma at work, and commuting to and from work were recorded. A limited evaluation of the reproducibility of work history data was conducted by telephone interview 12 months later (Battié et al. 1995). The subjects' responses to questions asked during the telephone interview were compared with their responses to questions asked during the initial interview for those who noted that their job had not changed since that time. The Spearman correlation coefficients were 0.75 for sitting, 0.77 for driving, and 0.60 for total lifting per day (Battié et al. 1995).

4.2.2 Leisure-time physical activity

Interviewers reviewed the subjects' lifetime histories of regularly performed exercise and other leisure-time physical activities during at least three months per year as a part of the interview. Mode, length of time of participation (years during lifetime, months per year), duration (minutes per session), frequency (times per week), intensity (light, moderate, or strenuous), and associated injuries were recorded.

4.3 Back function tests (II, III, IV, V)

Three different aspects of back function were evaluated: isometric back extension endurance, psychophysical lifting capacity and isokinetic lifting performance. A trained physician or a physical therapist administered the tests to both twins within a pair. The back function tests were performed in a constant order: the isokinetic lifting was performed first, followed by the psychophysical lifting test and the isometric back extension endurance was done last. A three minutes resting period was provided between the tests and during the resting period, subjects were allowed to move freely or sit down.

4.3.1 The isokinetic lifting test (II, III, IV)

The isokinetic lifting test was performed from a forward-bending position with knees straight (Latikka et al. 1995). The forward-bending position was measured by use of an MIE goniometer on the L3 vertebra at 60° of spinal flexion. The MIE goniometer is commercially available and widely used by physiotherapists, with a reported inter-rater repeatability of ICC = 0.57 for flexion, 0.67 for extension, and 0.59 for prone extension in a non-patient sample (Chiarello & Savidge 1993). The inter-rater repeatability of spine range of motion has been slightly better among LBP patients, ICC = 0.76-0.86. The L3 vertebra was selected because it estimates best the spinal motion when the thoracic spine and pelvis are in a stationary position (Dvir 1991). The subjects received standardized instructions and a demonstration and were asked to lift their body as rapidly and forcefully as possible. No other encouragement was given. The isokinetic lifting device includes a platform with footprints 21 cm apart to stand on and a bar to lift 3 cm in front of footprints. To minimize the contribution of the arm and leg muscles in force production, the subjects kept their knees, wrists, and elbows straight (Figure 2). Prior to the four recorded lifts, subjects performed five training lifts at constant 0.5 m/s speed, the speed was available from the device. Between recorded lifts were 1-minute rest intervals. Lifting force was recorded (in Newton), and speed and height of the lift were entered to calculate work done (in joules). The best result was used in the subsequent analysis. The isokinetic lifting device was built in the University of Jyväskylä and had a precision gauge with a measurement error of 1% of maximum. The device was calibrated before and after every measurement session, four times per a day. The repeatability of isokinetic lifting performance was determined in a study of working-age adults with no known pathology or impairments, and ICCs of 0.97 and 0.87 were obtained for intratest and intertest repeatability of peak force and total work measurements (Latikka et al. 1995).

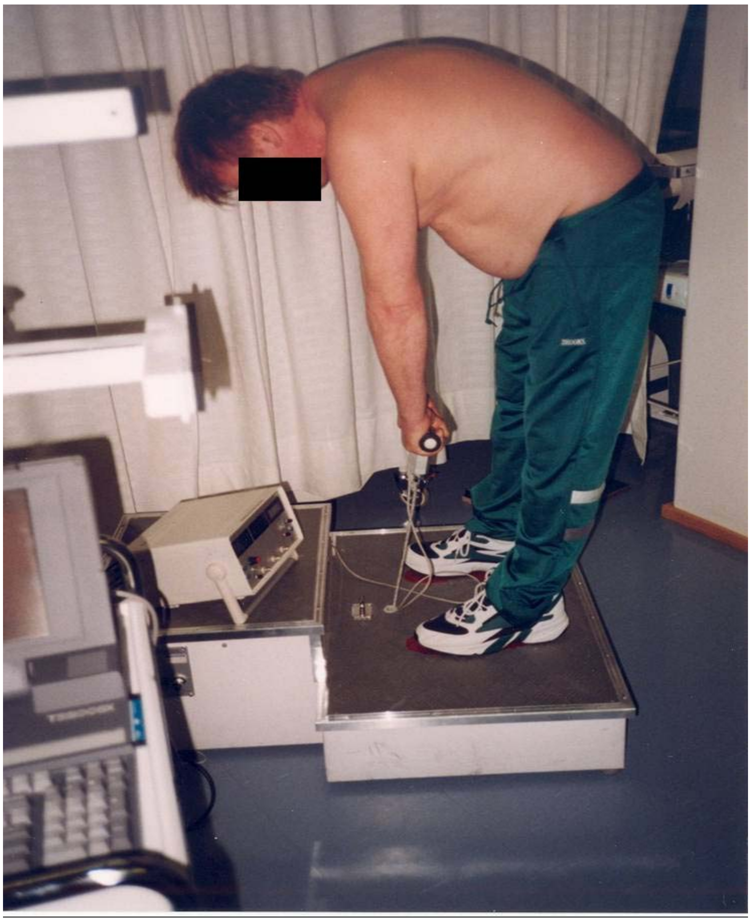

FIGURE 2 The test position and device for isokinetic and psychophysical lifting tests.

4.3.2 The psychophysical lifting test (III, IV)

The psychophysical lifting test was similar to the "acceptable isometric lifting force test" described by Foreman et al. (1984) except that the lifting position was at 60 ° of flexion instead of at knee level (Figure 2). According to Foreman et al., the "acceptable" lifting force is the maximum force a subject exhibits when asked to demonstrate the maximum force that he or she can comfortably maintain for 5 seconds. Sixty degrees of flexion was selected to standardize the test position for psychophysical lifting test as described in detail for the isokinetic lifting test, and the device was the same. Subjects were asked to use the maximum force (in Newton) they thought they could comfortably maintain for 5 seconds while performing the isometric lift. No encouragement was given. The subjects kept their knees and elbows straight for three lifts, with short rest intervals (approximately 5 seconds) between lifts. Pearson correlation coefficients of 0.87 to 0.96 were reported for intertester repeatability of measurements among working-age subjects with no known pathology or impairments (Foreman et al. 1984, Troup et al. 1986).

4.3.3 Isometric back extension endurance (III, IV, V)

The isometric back extension endurance test was performed by subjects holding their unsupported upper body (from the anterior iliac crests level up) horizontal while prone, feet secured with two broad straps (Biering-Sorensen 1984) with their hands held behind the neck. During testing, subjects received encouragement once if their position fell below the horizontal level as indicated by a plumb bob hanging from the ceiling that was adjusted to contact the back when the horizontal position was maintained (Figure 3). A deviation of one centimeter was allowed. If the position was not immediately corrected, or if the subject claimed he could no longer hold the position due to fatigue or discomfort, the test was ended and holding time (in seconds) was recorded. Pearson correlation coefficients for intertest repeatability have ranged from 0.66 to 0.89 in earlier studies (Jörgensen & Nicolaisen 1987, Alaranta et al. 1994).

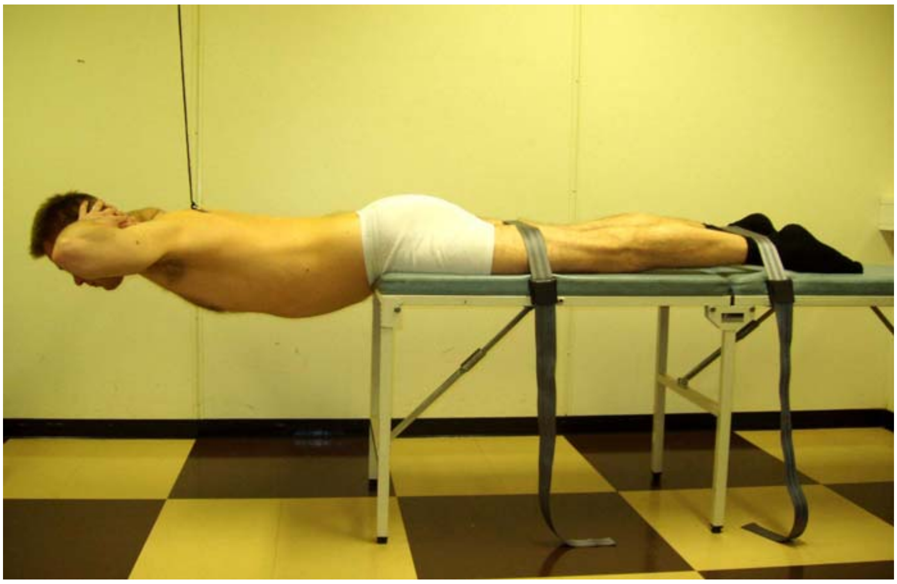

FIGURE **3** The test position of the isometric back extension endurance test.

4.4 Body fat measurement (II, IV)

Bioelectric impedance was used to obtain percentage of body fat (%) following the manufacturer's instructions (Spectrum II, RJL Systems, Detroit, MI, USA) and electrode settings as described in detail by Van Loan (1990). This method is based on the behavior of biological structures subjected to a constant low-level alternating current (Van Loan 1990). The coefficient of variation between two consecutive bioelectrical impedance analysis measurements has been in the range 0.2-4.1% (Van Loan 1990, Vehrs et al. 1998). The construct validity of bioelectrical impedance analysis measurements of adults has been published (Janssen et al. 2000) assuming pre-testing and testing procedures are well standardized (Broeder et al. 1997) and the bioelectrical impedance analysis prediction equation is population-specific (Ravaglia et al. 1999, Janssen et al. 2000). Lean body mass (kg) was computed based on the percentage of body fat and was calculated by subtracting fat weight (kg) from total body weight (kg).

4.5 Magnetic resonance imaging (II, III)

MRI was used to analyze paraspinal muscle CSA (cm^2). Subjects were positioned supine on the MRI equipment and the imaging protocol took about 25-30 minutes per subject. Transverse sections were obtained for lumbar levels L2 to S1 using a 1.5-T Siemens Magnetom MR imager (Siemens AG, Erlangen, Germany) with a surface coil, using a sequence SE 2450/90. Slice thickness was 3 mm and the gaps between the slices were 0.3 mm. The matrix was 192x256 and field of view (FOV) was 260 mm. The perimeters of the left and right erector spinae (later referred to as erector muscle), quadratus lumborum, and psoas major muscles were traced with a cursor by the author, and the traced regions of interest were analyzed digitally. The erector muscle was traced as the whole area occupied by multifidus, longissimus and iliocostalis, which lie adjacent to each other, including the non-muscular tissue between them. Muscle perimeters were traced, excluding clear cavities of fat at the periphery of the muscle area. Muscle CSA measures at the level of L3-L4 disc and on the left and right side muscle were selected for the analysis because the paraspinal muscle CSAs have previously been found to be largest overall at the L3-L4 level (Käser et al. 2001, Marras et al. 2001b). No correction was made for the digitized area because the differences between digitally obtained areas and true anatomical areas previously have been found to be small (< 3%) (McGill et al. 1993).

The sequence 2450/90 indicate that the low intensity pixels based on signal threshold are likely to originate from muscle tissue (with a high water content) and high intensity pixels based on signal intensity are from tissues with low water content such as connective tissue and in particular fat (non-muscle tissue). The threshold signal intensity value separating muscle (lower intensity pixels) from fat and connective tissue (high intensity pixels) was selected based on the bi-modal distribution of signal intensities and confirmed from sampling of intensities from the image data using a custom-made spine image analysis program. Images from L5-S1 were omitted from the analysis due to the effect of lumbar curvature (lordosis) on the angle of muscles and their CSA measurements. Some of the subjects had no visible quadratus lumborum muscle at level L4-L5 and, therefore, quadratus lumborum CSA measurements at that level were excluded from the statistical analysis for those subjects. There were some images with low visibility in regions most distal from the coil, which may have affected the tracing of the psoas major perimeters that were farthest from the coil.

The intra-rater repeatability was tested with MR images from L3-L4 level of the paraspinal muscle CSA of 169 subjects and composition measurements based on signal intensity of 32 randomly selected subjects in two sessions performed 4 to 8 weeks apart. The subjects' MR images were placed in a random order for the second evaluation and the measurer was blinded to the results of the first session. The whole cross-sectional area of a muscle was traced (Figure 2). After the CSA of the muscle was traced, the mean signal intensity was obtained as an indicator of muscle composition (quantitative measurement). The mean muscle signal intensity was adjusted (divided) by the signal intensity of the adjacent cerebrospinal fluid (CSF), which provided an intra-body reference to diminish the variations caused by magnetic field inhomogeneity and to improve comparisons between subjects of measures using signal intensity (see in detail Battié et al. 1995). Thus higher values represented higher non-muscle or fat composition. Muscle CSA was then adjusted by this value for analyses of association with isokinetic lifting.

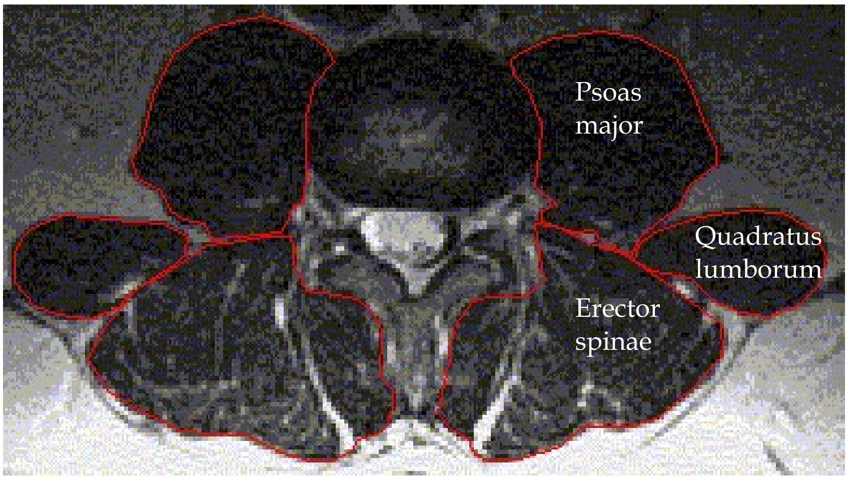

FIGURE 4 Axial MR image at the level of the L3-L4 disc with tracing around the erector, quadratus lumborum and psoas major muscles.

Qualitative ratings of non-muscle tissue area within the entire muscle area (qualitative measure) were done for erector, psoas major and quadratus lumborum muscles at L3-L4 level with a 4-point visual scale (0 = only muscle tissue, 1 = minor deposits of non-muscle tissue, 2 = moderate areas of non-muscle tissue, and 3 = large areas of non-muscle tissue) for the randomly selected 32 subjects (Table 4). The non-muscle tissue was identified as pixels of light color (white or light gray) within the muscle cross-sectional area, while darker gray pixels represented muscle tissue. After tracing all the muscles, the images for the examples of the ratings were selected (i.e. the muscle representing the zero in the 4-point scale). Each muscle was then compared to the examples to achieve consistent results for each point on the scale. The qualitative ratings were done twice and the mean of the two measurements was used for the subsequent analyses. Muscle CSA was also adjusted by the qualitative rating for analyses of association with isokinetic lifting.

TABLE 4 Frequencies (%) for qualitative rating of non-muscle tissue within erector, psoas major and quadratus lumborum muscles

Muscle	Only muscle tissue	Minor deposits of non-muscle tissue	Moderate amount of non-muscle tissue	High amount of non-muscle tissue
Erector L2-L3	9 (18)	21 (43)	17 (35)	2 (4)
L3-L4	7 (14)	18 (37)	20 (41)	4 (8)
L4-L5	4 (8)	18 (37)	19 (39)	8 (16)
Psoas L2-L3	38 (83)	8 (17)		
L3-L4	33 (72)	13 (28)		
L4-L5	20 (44)	25 (54)	1 (2)	
Quadratus L2-L3	39 (78)	11 (22)		
L3-L4	35 (70)	15 (30)		
L4-L5	1 (14)	3 (43)	3 (43)	

4.6 Statistics

In all the analyses, the assumption of Gaussian normal distribution was tested and non-normal variables were transformed (CSA variables, isometric back extension endurance test and anthropometric measures) or categorized (physical activity variables). Intra-class correlation coefficients (ICCs) were calculated to evaluate test-retest repeatability of the quantitative measures of muscle CSA and the mean signal intensity values using a formula based on a two-way analysis of variance with a separate error within the factor (Strout & Fleiss 1979). Weighted Kappa coefficients (Dunn 1989) were estimated for test-retest variables of qualitative ratings of non-muscle tissue within a muscle. The scale of Landis and Koch (1977) indicates that the strength of agreement should be interpreted as follows 0.00-0.20 = poor, 0.21-0.40 = fair, 0.41-0.60 = moderate, 0.61-0.80 = good, and 0.81-1.00 = excellent.

Associations of anthropometrics, paraspinal muscle CSAs and physical activity parameters with isokinetic and psychophysical lifting capacity and isometric back extension endurance tests were analysed by backwards stepwise regression estimation (Stata 2004). All the factors were entered into model at once. The contribution of each particular factor to the current model was checked with the P value, with the factor with the highest P value (lowest significance) in each step being removed. The analysis continued until all factors in the model contributed significantly at the 0.05 level.

For the analysis of heredity and shared and unique influences in the back function tests, the equality of means of continuous variables by zygosity and proportions of binary variables were tested using an adjusted Wald test to take into account the fact that the twin individuals had been sampled as twin pairs and thus did not represent fully independent observations (Stata 2004). The equality of variances of continuous variables was tested using the variance ratio test and the equality of distributions of categorical variables by zygosity was tested using a design-based independence test, equivalent to a chi-square test of independence but taking the sampling design into account (Rao & Scott 1981). The effect of age on back muscle performance test results among twin individuals was modeled using a survey regression model that takes into account the covariance within twin pairs and calculates the proportion explained by age, *P* value, 95% confidence interval (CI) of regression coefficient, and 95% CI of regression constant adjusted to that within-pair covariance. In univariate analyses of continuous variables, data were summarized with covariance matrices and means, and models were fitted using the maximum likelihood estimation method. In the data analysis with binary or categorical variables, data were summarized to polychoric correlations, asymptotic variances, and asymptotic covariance, while models were fit using asymptotic weighted least-squares estimation. The Mx statistical program for twin and family data was used for all estimations (Neale 1994).

Variables associated with stopping due to fatigue, rather than LBP, were assessed using logistic regression. Odds ratios and 95% confidence intervals were calculated, with the standard errors adjusted for clustering by twin pair. Linear regression, adjusted for twin pair, was used to estimate the difference in length of holding times between the two groups.

5 RESULTS

Means for back function tests, paraspinal muscles CSAs and physical activity parameters are shown in Table 5.

5.1 Measures of reproducibility

The repeatability of lifetime physical activity parameters was highest for the exercise years, ICC = 0.88, and mean hours/week for the mode of the most commonly performed exercise, ICC = 0.90. Also mean lifetime exercise years ICC = 0.69 and exercise hours/week ICC = 0.73 yielded high repeatability. Lifetime frequency (times/week) and sum of minutes/session showed acceptable repeatability, ICC = 0.44-0.64.

Means of back muscle performance tests, paraspinal muscle CSAs and physical activity parameters are shown in Table 4. Erector muscle CSA was largest at L2-L3 and L3-L4 levels (mean 25.1 cm^2 and 24.6 cm^2, respectively). Psoas major CSA was largest at L4-L5 and quadratus lumborum at L3-L4. Left side muscle CSA means were 4-10% larger than those on the right at each level ($p < 0.01$).

The intra-rater repeatability of total muscle CSAs at L3-L4 level was excellent for erector, quadratus lumborum and psoas major muscles (ICC = 0.95-0.99). Repeatability of the mean signal intensity of the traced areas was excellent in erector, psoas major and quadratus lumborum muscles (ICC = 0.97-0.99). For qualitative muscle composition ratings of non-muscle tissue, the repeatability was good in erector (Kappa = 0.63) and quadratus lumborum muscles (Kappa 0.66), and moderate in psoas major muscle (Kappa = 0.51).

TABLE 5 Means (95% confidence interval [95% CI]) for back function tests, paraspinal muscles CSAs and physical activity parameters

Variables	n	Means (95% CI)
Back function tests		
Psychophysical lifting capacity (N)	210	422 (405-439)
Isometric back extension endurance (s)	210	75 (71-79)
Isokinetic lifting force (N)	210	996 (972-1019)
Isokinetic lifting work (J)	210	456 (436-476)
Paraspinal muscle cross-sectional areas by disc level		
L2-L3 Erector muscle (cm^2)	210	25.1 (24.4–25.8)
Psoas major	210	8.6 (8.3–8.9)
Quadratus lumborum	209	5.9 (5.6–6.1)
Sum of paraspinal muscle CSAs	209	39.5 ((38.7-60.6)
L3-L4 Erector muscle	210	24.6 (23.9–25.3)
Psoas major	210	12.9 (12.5–13.3)
Quadratus lumborum	207	7.1 (6.8–7.3)
Sum of paraspinal muscle CSAs	207	44.6 (29.4-68.6)
L4-L5 Erector muscle	208	16.4 (15.9–16.9)
Psoas major	206	21.9 (21.1–22.7)
Quadratus lumborum	76	6.8 (6.3–7.3)
Sum of paraspinal muscle CSAs	76	45.9 (30.6-68.0)
Physical activity parameters		
Aerobic sport during past year, ≥2 times/wk, every week (months/year)	209	8 (7-9)
Aerobic sport during years after age 12, ≥2 times/wk (years)	209	18 (16-20)
Resistance training during past year, ≥2 times/wk every wk (months/year)	209	0.3 (0.1-0.5)
Resistance training during years after age 12, ≥2 times/wk (years)	209	0.7 (0.4-1.0)
Other heavy leisure time activities during past year, ≥2 times/wk, every wk (months/year)	209	8 (6-9)
Other heavy leisure time activities during years after age 12, ≥2 times/wk (years)	209	11 (10-13)
Occupational physical loading, past year¤	209	4 (4.1-4.6)
Occupational physical loading, life time mean¤	209	4 (4.0-4.5)

¤ Occupational loading was a categorical variable, with scale 1-5, where 1 = retired or unemployed, 2 = sedentary, 3 = light mixed, 4 = heavy mixed, 5 = heavy

5.2 Measures of construct validity

Qualitative muscle composition rating of non-muscle tissue in erector muscle showed a fair association with body fat (r = 0.41, p < 0.01). However, the associations of different muscle composition measurements with isokinetic lifting performance were weak (r = -0.02- 0.45) (Table 6). The amount of fat within paraspinal muscles as indicated by qualitative muscle composition rating exhibited the best, but still only a weak to moderate negative association with isokinetic lifting performance (r = -0.19- -0.41).

TABLE 6 Correlations of quantitative and qualitative muscle composition measurements of erector, psoas major and quadratus lumborum muscles with isokinetic lifting performance

Muscle composition measurements	**Isokinetic lifting** **Force**	 **Work**
Erector muscle		
Total CSA (cm^2)	**0.21***	**0.17***
adjusted for CSF‡	0.19*	0.16
adjusted for qualitative ratings†	0.23	-0.02
Mean signal intensity adjusted for CSF	**0.14**	**0.08**
Qualitative ratings†	**-0.25**	**-0.41****
Psoas major		
Total CSA (cm^2)	**0.31*****	**0.32*****
adjusted for CSF‡	0.32***	0.33***
adjusted for qualitative ratings†	0.45*	0.31
Mean signal intensity adjusted for CSF	**0.15**	**0.11**
Qualitative ratings†	**-0.19**	**-0.23**
Quadratus lumborum		
Total CSA (cm^2)	**0.26****	**0.22****
adjusted for CSF‡	0.22**	0.27***
adjusted for qualitative ratings†	0.08	0.08
Mean signal intensity adjusted for CSF	**0.15**	**0.10**
Qualitative ratings†	**-0.34***	**-0.30**

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

Values with bold face are unadjusted Pearson correlation coefficients

† Kendall's rank correlation coefficient tau-b

‡ CSA adjusted by the signal intensity of that area divided by the signal intensity of adjacent cerebrospinal fluid (CSF)

5.3 Contributors of isokinetic lifting performance

The association of paraspinal muscle CSAs, anthropometric measures and physical activity parameters with isokinetic lifting performance was first studied in a univariate analysis without taking into account heredity. The variance in isokinetic lifting performance explained by paraspinal muscle CSAs was highest in the values measured from L3-L4. Paraspinal muscles CSAs or their combination explained 12-25% of isokinetic lifting force, but clearly less of the isokinetic lifting work (4-15%, Table 6). With respect to anthropometric measures, lean body mass and body weight explained 17-24% of variance in isokinetic lifting performance. Using backward stepwise analysis several models were developed to predict isokinetic lifting performance (Table 7). The final parsimonious model including age, lean body weight, CSA of psoas major and the sum of paraspinal CSAs at L3-L4 level predicted 33% of the isokinetic lifting force. For isokinetic lifting work, the final parsimonious model including age, body weight and the sum of paraspinal CSAs predicted 29%.

Then the genetic and common and unique environmental (later referred to constitutional and behavioral factors) variance components for isokinetic lifting performance were estimated by standard univariate twin analysis. The model resulting in the lowest Akaike's information criteria (AIC = -1.28, χ^2 = 4.73) for isokinetic lifting force was the model consisting of heredity, unique constitutional and behavioral factors and age effects. Genetic factors had the greatest single influence, explaining 56% of the variance in the isokinetic lifting force. Unique factors accounted for 36% of the variance, but common constitutional and behavioral factors made no contribution (Table 8). The proportion of variance explained by 10 years of additional age was 7%. For isokinetic lifting work, the model resulting in the lowest AIC (-0.44, χ^2 = 7.56) was the model with heredity, unique constitutional and behavioral factors and age effects. Genetic factors explained 41% of variance, unique factors explained 44% and the proportion of variance explained by 10 years of additional age was 15% (Table 8).

The proportion of the variance that the unique constitutional and behavioral factors accounted for in the factors evaluated in isokinetic lifting force was 11% for body weight, 1% for self-assessed health compared with others of the same age, 2% for physical loading at work, and 4% for participation in resistance training. The proportion of variance of common constitutional and behavioral factors explained by the studied factors in isokinetic lifting force was 2% for other leisure-time physical activities and 36% for body weight. In isokinetic lifting work, the proportion of variance of unique constitutional and behavioral factors accounted for by the studied factors was 8% for body weight, 2% for occupational physical loading, and 41% for resistance training. The proportion of variance in isokinetic lifting work explained by common constitutional and behavioral factors of this study was 1% for education, 5% for resistance training and 32% for body weight.

TABLE 7 The proportions of variances of the isokinetic lifting test results explained by body weight, lean body weight, BMI, lean BMI, cross-sectional areas at the spinal levels of erector, quadratus lumborum, psoas major and the sum of all measured paraspinal muscles CSAs, different physical activity parameters, and past and current occupational physical loading (from univariate analysis)

	Isokinetic lifting force		**Isokinetic lifting work**	
Parameter	**Univariate associations**	**Multivariate associations**	**Univariate associations**	**Multivariate associations**
	R^2 (p-value)	**R^2 (p-value)**	**R^2 (p-value)**	**R^2 (p-value)**
Age	5.7 (< 0.001)	5.7 (< 0.01)	13.0 (< 0.001)	13.0 (< 0.001)
Anthropometric measures				
Height	12.1 (< 0.001)	0 (0.81)	11.0 (< 0.001)	0.7 (0.17)
Body weight	20.8 (< 0.001)	0.8 (0.15)	17.1 (< 0.001)	14.3 (< 0.001)
Lean body weight	23.7 (< 0.001)	21.3 (< 0.001)	16.6 (< 0.001)	0.2 (0.51)
BMI	10.3 (< 0.001)	0.7 (0.20)	8.1 (< 0.001)	0.1 (0.58)
Fat%	0.9		1.8	
Lean BMI	11.6 (< 0.001)	0.2 (0.54)	6.8 (< 0.001)	0.4 (0.50)
Total		**26.1 (< 0.001)**		**28.8 (< 0.001)**
Paraspinal muscle CSAs by disc level				
Erector muscle				
L2-L3 level	16.2 (< 0.01)		10.4 (< 0.001)	
L3-L4 level	14.8 (< 0.001)	0.1 (0.71)	12.0 (< 0.001)	0.1 (0.71)
L4-L5 level	5.6 (< 0.01)		7.0 (< 0.001)	
Psoas major				
L2-L3 level	13.5 (< 0.001)		6.7 (< 0.001)	
L3-L4 level	21.4 (< 0.001)	2.3 (< 0.05)	10.8 (< 0.001)	
L4-L5 level	19.1 (< 0.001)		11.8 (< 0.001)	
Quadratus lumborum				
L2-L3 level	10.7 (< 0.001)		4.1 (< 0.05)	
L3-L4 level	12.1 (< 0.001)		3.6 (< 0.05)	
L4-L5 level	0.9		0.7	
Sum of paraspinal muscle CSAs by disc level				
Sum of paraspinal muscle CSAs at L2-L3 level	20.4(< 0.001)		12.8 (< 0.001)	
Sum of paraspinal muscle CSAs at L3-L4 level	24.8 (< 0.001)	24.8 (< 0.001)	15.4 (< 0.001)	12.2 (< 0.001)
Sum of paraspinal muscle CSAs at L4-L5 level	8.3 (< 0.05)		10.6 (< 0.05)	

TABLE 7 continues

Parameter	Isokinetic lifting force Univariate associations	 Multivariate associations	Isokinetic lifting work Univariate associations	 Multivariate associations
	R^2 (p-value)	**R^2 (p-value)**	**R^2 (p-value)**	**R^2 (p-value)**
Total		**30.6**		**26.7 (< 0.001)**
Physical activity variables			1.0	
Resting heart rate	1.0	0.5 (0.14)	0.8	
Aerobic sport during past year, >=2 times/wk, every wk	0.8	1.0 (0.15)	1.0	1.1 (0.11)
Aerobic sport during years after age 12, >=2 times/wk	1.3		2.8	
Resistance training during past year, >=2 times/wk	1.5		2.2 (< 0.05)	2.3 (< 0.05)
Resistance training during years after age 12, >=2 times/wk	0.6		0.1	
Other heavy leisure time activities during past year, >=2 times/wk, every wk	0.3		0.4	
Other heavy leisure time activities during years after age 12, >=2 times/wk	1.3		2.0 (< 0.05)	1.0 (0.28)
Occupational physical loading, past year	0.3	6.1 (0.26)	0.5	4.1 (0.26)
Occupational physical loading, life time mean	1.0	1.3 (0.23)		
Total		**16.7 (0.06)**		**22.5 (< 0.01)**

TABLE 8 Variance component models for isokinetic lifting performance: fit statistics and variance component estimates (95% confidence intervals) for additive genetic (a^2), dominance genetic (d^2), unique environment (e^2) and effect of age (s^2).

	Standardized Coefficient (95%CI)				**Goodness-of-Fit Tests**			
Model	**a^2**	**d^2**	**e^2**	**s^2**	**χ^2**	**degrees of freedom**	**P-value**	**AIC**
Isokinetic lifting force								
ADE	0.27 (0.00 - 0.69)	0.37 (0.00 - 0.72)	0.36 (0.28 - 0.46)	-	30.69	4	< 0.001	22.69
ADES[#]	**0.15 (0.00 - 0.62)**	**0.42 (0.00 - 0.66)**	**0.36 (0.28 - 0.47)**	**0.07 (0.03 - 0.12)**	**4.73**	**3**	**0.19**	**-1.28**
AE	0.63 (0.52 - 0.71)	-	0.37 (0.29 - 0.48)	-	32.01	5	< 0.001	22.01
AES[¤]	0.55 (0.43 - 0.64)	-	0.38 (0.30 - 0.49)	0.07 (0.03 - 0.13)	6.68	4	0.15	-1.32
Isokinetic lifting work								
ADE	0.43 (0.00 - 0.67)	0.16 (0.00 – 0.68)	0.41 (0.32 - 0.52)	-	64.03	4	< 0.001	56.03
ADES[¤]	0.17 (0.00 - 0.51)	0.26 (0.00 - 0.54)	0.42 (0.33 - 0.55)	0.14 (0.09 - 0.21)	6.71	3	0.08	.71
AE	0.59 (0.48 - 0.67)	-	0.42 (0.33 - 0.53)	-	64.27	5	< 0.000	54.27
AES[¤]	**0.41 (0.29 - 0.52)**	**-**	**0.44 (0.29 - 0.52)**	**0.15 (0.09 - 0.21)**	**7.56**	**4**	**0.11**	**-.44**

¤ Regression coefficient s= -0.379, 95%CI= -0.457 - -0.292

Regression coefficient s= -0.263, 95%CI= -0.352 - -0.166

5.4 Contributors of psychophysical lifting capacity

The contributors to the variance in psychophysical lifting capacity in the analysis without heredity are shown in Table 9. Paraspinal CSAs explained 1-9% at L3-L4 level, anthropometric measures accounted for 4-10% and physical activity parameters only 0-2% of the variance. The full anthropometric measures model explained 14%, the full paraspinal CSA model 9% and the full physical activity model accounted for 15%. The final parsimonious model including lean body weight and past year occupational physical loading explained 13% of the psychophysical lifting capacity (Table 9).

The univariate twin analysis showed that the model resulting in the lowest AIC (-2.63, $\chi^2 = 5.37$) for psychophysical lifting capacity was the model with heredity and unique constitutional and behavioral factors. Heredity explained 51% and unique constitutional and behavioral factors accounted for 49% of the variance in the psychophysical lifting capacity (Table 10). Ten years of additional age had no influence on psychophysical lifting capacity. Taking heredity into account, the proportion of variance of unique constitutional and behavioral factors that the studied factors accounted for in psychophysical lifting capacity was estimated to be 2% for self-assessed health compared to the others same aged individuals, 4% for occupational physical loading, and 1% for resistance training. One common constitutional factor was body weight, explaining 37% of the variance in the psychophysical lifting capacity.

TABLE 9 The proportions of variances of the psychophysical lifting and isometric back extension endurance test results explained by body weight, lean body weight, BMI, lean BMI, cross-sectional areas at the spinal levels of erector, quadratus lumborum, psoas major and the sum of all measured paraspinal muscles CSAs, different physical activity parameters, and past and current occupational physical loading (from univariate analysis)

	Psychophysical lifting capacity		**Isometric back extension endurance**	
Parameter	**Univariate associations**	**Multivariate associations**	**Univariate associations**	**Multivariate associations**
	R^2 (p-value)	**R^2 (p-value)**	**R^2 (p-value)**	**R^2 (p-value)**
Age	0.2	0 (0.64)	6.3 (< 0.001)	6.3 (< 0.001)
Anthropometric measures				
Height	2.2(< 0.01)	0 (0.85)	0	1.0 (0.80)
Body weight	6.2 (< 0.001)	2.3 (0.48)	1.3	0
Lean body weight	10.3 (< 0.001)	9.8 (< 0.001)	0	0.2
BMI	4.1 (< 0.01)	0.1 (0.68)	2.1 (< 0.05)	3.8 (< 0.01)
Fat%	0.1		2.4	
Lean BMI	8.0 (< 0.001)	3.4 (0.57)	0.5	0
Total		**13.6 (< 0.001)**		**10.5 (< 0.01)**
Paraspinal muscle CSAs by disc level				
Erector muscle				
L2-L3 level	7.4 (< 0.001)		0.1	
L3-L4 level	7.3 (< 0.001)	1.0 (0.53)	0.3	
L4-L5 level	2.8 (< 0.05)		0	
Psoas major				
L2-L3 level	3.1 (< 0.01)		0.7	
L3-L4 level	3.6 (< 0.05)		2.1	0.5 (0.29)
L4-L5 level	1.6		4.9 (< 0.01)	

TABLE 9 continues

Parameter	Psychophysical lifting capacity		Isometric back extension endurance	
	Univariate associations	Multivariate associations	Univariate associations	Multivariate associations
	R^2 (p-value)	R^2 (p-value)	R^2 (p-value)	R^2 (p-value)
Quadratus lumborum				
L2-L3 level	3.9 (< 0.05)		0	
L3-L4 level	0.8		0	
L4-L5 level	0.4		4.7	
Sum of paraspinal muscle CSAs by disc level				
Sum of paraspinal muscle CSAs at L2-L3 level	8.9 (< 0.001)		0	
Sum of paraspinal muscle CSAs at L3-L4 level	7.5 (< 0.001)	7.5 (< 0.001)	0.4	
Sum of paraspinal muscle CSAs at L4-L5 level	4.0		0.7	
Total		**8.5 (0.01)**		**7.3 (< 0.01)**
Physical activity variables				
Resting heart rate	0.2		0	2.3 (< 0.05)
Aerobic sport during past year, >=2 times/wk, every wk	1.2		0.3	
Aerobic sport during years after age 12, >=2 times/wk	2.3		0	
Resistance training during past year, >=2 times/wk	0.2	1.2 (0.19)	4.9 (< 0.05)	1.3 (0.10)
Resistance training during years after age 12, >=2 times/wk	0.8	2.4 (< 0.05)	2.4 (< 0.05)	
Other heavy leisure time activities during past year, >=2 times/wk, every wk	0.7	0.9 (0.17)	0	0 (0.9)
Other heavy leisure time activities during years after age 12, >=2 times/wk	0		0	1.0 (0.27)
Occupational physical loading, past year	0.3 (< 0.05)	4.6 (0.3)	5.5 (< 0.001)	8.6 (0.32)
Occupational physical loading, life time mean	0.1	2.9 (< 0.05)	1.7	
Total		**14.6 (0.6)**		**20.1 (< 0.01)**

TABLE 10 Variance component models for psychophysical lifting capacity: fit statistics and variance component estimates (95% confidence intervals) for common environment (c^2), unique environment (e^2) and effect of age (s^2).

	Standardized Coefficient (95%CI)					Goodness-of-Fit Tests			
Model	**d^2**	**a^2**	**c^2**	**e^2**	**s^2**	**χ^2**	**Degrees of Freedom**	**P-value**	**AIC**
ADES	0.00 (0.00 - 0.30)	0.51 (0.21 - 0.60)	-	0.49 (0.40 - 0.61)	0.00 (0.00 - 0.02)	5.37	3	0.15	-.63
ACE	-	0.15 (0.00 - 0.53)	0.32 (0.00 - 0.51)	0.53 (0.42 - 0.66)	-	1.83	4	0.77	-6.17
ACES#	-	0.15 (0.00 - 0.53)	0.32 (0.00 - 0.51)	0.53 (0.42 - 0.66)	0.00 (0.00 - 0.02)	1.63	3	0.65	-4.37
AES	-	**0.51 (0.39 - 0.60)**	**-**	**0.49 (0.40 - 0.61)**	**0.00 (0.00 - 0.02)**	**5.37**	**4**	**0.25**	**-2.63**
CES	-	-	0.43 (0.33 - 0.51)	0.57 (0.49 - 0.67)	0.00 (0.00 - 0.02)	2.27	4	0.69	-5.73
ES	-	-	-	1.00 (0.99 – 1.00)	0.00 (0.00 - 0.01)	53.49	5	< 0.001	41.49

Regression coefficient s= -0.024, 95%CI= -0.125 , 0.080

5.5 Contributors of isometric back extension endurance

First, we performed the analysis of the anthropometric and physical activity factors not taking heredity into account. In the full model including all the possible parameters examined in this study paraspinal muscle CSAs explained 7%, the full model of anthropometric measures explained 11% and the full model of physical activity parameters accounted for 20% of the variance in isometric back extension endurance (Table 9). The best model for predicting isometric back extension endurance of these factors was the combined model including age, anthropometric measures and physical activity parameters, explaining 13%.

Subsequently, the univariate twin analysis was performed. The model resulting in the lowest AIC (3.83, χ^2 = 11.83) for isometric back extension endurance was a model with common (i.e. properties shared by both twins) and unique (i.e. properties distinct to one of the twins) constitutional and behavioral factors and age effects. Common constitutional and common behavioral factors explained 35% and unique constitutional and unique behavioral factors 61% of the variance in isometric back extension endurance (Table 11). The proportion of variance explained by 10 years of additional age was 4%. When heredity was taken into account, the proportion of variance of unique constitutional and behavioral factors explained by this study was 10% for body weight, 6% for self-assessed health compared to the other individuals of the same age, 2% for aerobic sports, 7% for resistance training, and 5% for the reason of ending the isometric endurance test. A large proportion of variance of common constitutional and behavioral factors could not be allocated to any of the factors evaluated in this study.

To further explore the factors associated with isometric back extension endurance, the reasons for test termination in isometric back extension endurance test were studied. Fatigue was the main reason (63%) given for stopping, followed by acute pain in the lower extremities (13%), LBP (3%) during the test and other reasons, such as motivation, discomfort in the upper part of the body and anxiety. Those with current LBP (66%) reported fatigue as the reason for termination less than those who had never experienced LBP lasting more than one day (73%) showing a weak trend ($p = 0.17$) that LBP as reason for termination increased when the frequency of LBP increased. Also characteristics of the LBP, namely presence, frequency and intensity of LBP, were all significantly associated with the reason for terminating the isometric back extension endurance testing ($p < 0.001$); with subjects stopping due to fatigue reporting less LBP (Table 12). Daily LBP in the past year was also significantly associated with a greater likelihood of termination due to LBP [OR 0.12 (0.04, 0.36), $p < 0.001$]. None of the other variables studied was associated with the reason for test termination in univariate analyses.

Finally, for the two main reasons of test termination, fatigue vs. LBP were assessed in a multivariate model with history of competitive sports, and intensity and frequency of LBP during the past year were evaluated as contributory factors. With respect to LBP characteristics, higher pain intensity and frequency over the past year were significantly more likely to predict LBP as the reason for termination (Table 12). Controlling for LBP revealed a history of competitive sports as a factor predicting LBP as the reason for termination. A competitive sport history resulted in 14 sec (95%CI 5, 23) greater holding time compared to the result in individuals with no competitive sport history. Also a longer holding time was associated with stopping due to fatigue (rather than LBP), with a trend of 19 sec (95%CI -2, 40) longer time.

TABLE 11 Variance component models for isometric back extension endurance: fit statistics and variance component estimates (95% confidence intervals) for common environment (c^2), unique environment (e^2) and effect of age (s^2).

	Standardized Coefficients (95%CI)					**Goodness-of-Fit Tests**			
Model	**d^2**	**a^2**	**c^2**	**e^2**	**s^2**	**χ^2**	**degrees of freedom**	**P-value**	**AIC**
ADES	0.00 (0.00 - 0.20)	0.39 (0.18 - 0.50)	-	0.58 (0.47 - 0.71)	0.03 (0.01 - 0.06)	20.46	3	< 0.001	14.46
ACE	-	0.00 (0.00 - 0.31)	0.39 (0.12 - 0.48)	0.62 (0.51 - 0.72)	-	28.97	4	< 0.001	20.97
ACES#	-	0.00 (0.00 - 0.24)	0.35 (0.15 - 0.44)	0.61 (0.51 - 0.71)	0.04 (0.01 - 0.08)	11.83	3	0.01	5.83
AES	-	0.39 (0.26 - 0.50)	-	0.58 (0.47 - 0.71)	0.03 (0.01 - 0.06)	20.46	4	< 0.001	12.46
CES	**-**	**-**	**0.35 (0.25 - 0.44)**	**0.61 (0.52 - 0.71)**	**0.04 (0.01 - 0.08)**	**11.83**	**4**	**0.02**	**3.83**
ES	-	-	-	0.97 (0.95 – 0.99)	0.03 (0.01 - 0.05)	49.46	5	< 0.001	39.46

Regression coefficient s= -0.198, 95%ci= -0.274 , -0.109

TABLE 12 Univariate odds ratios and multivariate model for stopping due to fatigue, rather than LBP during the test.

	Univariate odds ratio	Multivariate model
	OR (95%CI)	**OR (95%CI)**
Holding time (1 minute longer)	2.12 (0.80, 5.63)	
Age (10 years older)	0.80 (0.46, 1.40)	
More frequent LBP past year (1 point/7)	0.61*** (0.47, 0.79)	0.16 (0.05, 0.54)
Higher LBP intensity past year (10 points/100) #	1.24*** (1.10, 1.39)	0.84 (0.74, 0.95)
LBP today	0.33* (0.13, 0.85)	
More tired than usual on the test day	1.03 (0.33, 3.20)	
Health currently normal on the test day	1.90 (0.60, 6.01)	
History of competitive sports	0.55 (0.22, 1.37)	0.38 (0.15, 0.98)
Years of aerobic exercise (10 years)¤	1.15 (0.87, 1.53)	

OR = Odds ratio, CI = confidence interval

¤years of aerobic activity are age-adjusted)

LBP intensity of worst episode of back symptoms over the prior year

*** $p < 0.001$, * $p < 0.05$

6 DISCUSSION

The goal of this doctorate project was to evaluate methodological aspects of selected tests of back muscle function and to explore some of the underlying factors suspected to influence the test results. Performance on the three tests was shown to be influenced by different determinants and the role of heredity varied significantly. In healthy subjects, only the isokinetic lifting tests results seemed to reflect the basic physical capacity for lifting. Psychophysical lifting and isometric back extension endurance tests might be more suitable for screening back related health status and the effects of treatment interventions or training.

6.1 General methodological considerations

One possible factor influencing results is the sample size. The selection of the subjects was carefully assessed for each study. The subjects were from a national population-based twin cohort (Kaprio & Koskenvuo 2002), which should be comparable to the general Finnish working age male population (Helakorpi et al. 2000). Women were excluded due to impossibility of finding sufficient female twin pairs with discordance in the factors that were considered in the initial study plan of the larger survey on the effects of common exposures on back and other musculoskeletal problems (Battié et al. 1995).

The MR images and subject sample obtained would seem to be adequate for investigating the associations between structure and function of the general adult male population. Subjects enrolled into the MRI study were not excluded based on any morbidity (except for the presence of metal parts in the body, which is a contraindication for MRI examination). The study groups of 169-210 men are larger than those used in previous studies of muscle CSA measured by MRI; these have ranged from 12 to 120 (Parkkola et al. 1992, Räty et al. 1999).

For investigating determinants of back function tests, subjects with diseases or symptoms which could possible limit or affect back function test performance were excluded. For instance, for the isometric back extension endurance test, those with medical problems other than LBP which could impair performance were excluded, leaving 544 men in the study of reasons for termination of the isometric back extension endurance and 504 men in the study into heredity and back function. A larger number of subjects would have provided more precise estimates by reducing dispersion and may have allowed a deeper insight into the factors designated as constitutional and behavioral accounting for the variance in back function tests. However, it is unlikely that increasing the number of subjects would have altered the conclusions. This large, population-based sample of men, including those with a history of LBP, current LBP, no LBP and a variety of constitutional and behavioral factors, is a major strength of this study.

6.1.1 Interview in relation to back function testing

The structured interview allowed us to obtain detailed information on the subjects' lifetime physical activities during leisure-time and at work from adolescence through adulthood. However, the degree to which the measurements accurately reflect the potential determinants of interest is largely unknown but inaccuracy always dilutes estimates of effect sizes. The unknown accuracy of retrospectively collected lifetime data has been a common problem, limiting the value of most epidemiological studies of the consequences of lifetime physical activity during leisure time or at work or while driving. For example, Lakka & Salonen (1992) showed that with respect to 12-month physical activity history, the poor ability to recall the duration and frequency of activities performed months earlier did reduce the repeatability of this type data collection.

The accuracy of both current and lifetime exercise data was investigated in this study to avoid some of the problems related to retrospective data collection. For the 5-year test-retest interval in this study, weekly exercise hours and years of participation were the most reliably measured variables, with ICCs ranging from 0.63 to 0.90. Several physical activity parameters considered in this study yielded a good to moderate repeatability coefficient for mean lifetime exercise hours/week ICC = 0.73, years of exercise ICC = 0.69 and modes of exercise ICC = 0.53. Similar to the results of this study, Friedenreich et al. (1998) and Chasan-Taber et al. (2002) have found that exercise hours per week (combining the information on duration and frequency) possessed high repeatability in their studies of the lifetime exercise history variables (r = 0.74 and ICC = 0.82, as compared to 0.73 found in this study). In general, the repeatability of the structured exercise interview data was similar to that of many other characteristics measured in epidemiological studies; i.e. spine loading during a single day (ICC = 0.81, Bakker et al. 2003), manual materials handling (r = 0.53-0.71, Wiktorin et al. 1996), lifetime alcohol consumption (ICC = 0.70-0.75, Friesema et al. 2004), and smoking (Kappa = 0.82-0.92, Brownson et al. 1999).

In addition, collecting data of the factors possibly related to performance might be influenced by common problems encountered when gathering interview data. A recent review (Shephard 2003) has addressed the main limitations of repeatability of physical activity questionnaires. Types (recreational vs. competitive), patterns (aerobic vs. resistance), intensity (absolute vs. relative), frequency (several vs. single bouts of exercise during a day), amount (duration), and environment (conditions) of physical activity have been investigated in several ways and therefore variations and inaccuracies in the measures will always dilute any physical activity questionnaire data. This was partially taken into account in this study by the use of the same interview for the whole study period and it was answered by all study subjects. The interview was designed to extract detailed information of physical activity both during leisure-time and at work, as well as separating more recreational types of exercise from competitive modes, assessing kinds of aerobic, resistance and other leisure-time physical activities, querying the frequency from the day to day level to years of exercise, and duration as minutes/session. This was achieved by using a structured interview carried out by five trained interviewers as a part of the systematic study protocol. All the responses were checked after the interview for inconsistencies and corrected by re-interviewing the subjects if necessary.

We tried to identify which physical activity parameters play a role in back function when heredity has been accounted for, in particular those depicting whole lifetime factors, such as regular resistance training. This study was one of the first to evaluate the effects of lifetime physical activity history on back function. The lifetime physical activity history was selected based on the previous results of Gibbons et al. (1997b) who reported that past year physical activity has only a minor role in the three back function tests assessed in this study. Also some evidence exists that lifetime physical activity data may be associated with back function related factors such as psychomotor reaction time (Simonen et al. 1998) and musculoskeletal symptoms (Holmberg et al. 2003). However, the behavioral factors considered in this study, such as current and lifetime physical activity explained only a minor proportion of the variance in back function tests. Thus, there must be some other factors playing more influential roles than those physical activity parameters considered in this study and evaluated by the interview.

6.1.2 Methodological considerations for back function tests

The comparability of results over time was taken into account in the MZ twin testing in 1991-1993 and DZ twin testing in 1997-1999, e.g. by using the same device, undertaking regular calibration of the testing device and ensuring standardization of the test protocol. The protocol included the same sequence of the back function tests. Isokinetic lifting test was performed first, the second test was the psychophysical lifting and the isometric back extension endurance test was the final test with a minimum of three minutes resting period between the tests when the subjects were allowed to move freely or sit down. The lifting test performances were monitored by the testers. The testers visually confirmed the extremities to be extended and that no flexion of the extremities was allowed during the lifting (see Figure 2). However, it does seem that some unidentified variations between the testing periods may have occurred, and that this influenced the results of why the participants terminated the isometric back extension endurance test and also modified the determination of the relative contributions of heredity. The means of back test results differed by zygosity and some of the difference was due to a "zygosity effect" because MZ twins share greater similarity than DZ twins. The similarity is due to the fact that MZ pairs share all genes, whereas DZ pairs share only half of their genes. The two same sex trained testers administered the trials during the six-year period of testing using the same testing device with a similar experimental protocol. However, the twins measured in 1991-1993 were tested by one tester, and the twins measured during 1997-1999 were tested by the second investigator. This resulted in the possibility of a "tester-effect," where subjects might have performed differently to the instructions given by one tester than they did in the presence of the other investigator.

6.2 Reproducibility of MRI parameters

We used the 1.5 Tesla MRI scanner and imaging sequences, which were selected in the early 1990's for intervertebral disc imaging and they were not changed in order to ensure the comparability within the larger study on the effects of common exposures on back and other musculoskeletal problems (Battié et al. 1995). The imaging sequences have been used also in other studies investigating paraspinal muscle composition (Räty et al. 1999, Ranson et al. 2005). In general, the repeatability of the CSA measures, quantitative measures and qualitative ratings of muscle composition of erector, psoas major and quadratus lumborum muscles was good to excellent which is in good agreement with previous studies of one level CSA measures (Gibbons et al. 1998, Peltonen et al. 1998, Kader et al. 2000, Marras et al. 2001b). However, associations of CSA and qualitative ratings and quantitative measures of muscle composition with isokinetic lifting performance varied from non-existent to moderate, highlighting the low sensitivity of these estimates for monitoring changes in isokinetic performance, a finding in agreement with other reports in the literature (Gibbons et al. 1997a, Mooney et al. 1997, Keller et al. 2003). These results suggest that both quantitative measure of muscle tissue and qualitative ratings of non-muscle tissue in paraspinal muscles are repeatable but low in construct validity for evaluation of different paraspinal muscles. It seems that either a more precise MR image evaluation program is needed to improve the accuracy of the muscle composition measures or that there are other, more influential factors than paraspinal muscle composition affecting the back function test results.

The high reproducibility of quantitative muscle composition measurements suggests that at least some of the difficulties related to tracing the muscle were overcome. The size of the areas of interest is believed to be a factor affecting reliable tracing of the muscles. Smaller areas and in particular with those with a long outline, contain relatively more pixels that are randomly included either to non-muscle tissue pixels or muscle tissue pixels. These areas are also most challenging to trace. In addition, a special problem is found in the psoas muscle, which is farthest from the coil, leading to problems with image quality (such as poor visibility due to distance from the coil) and these may have affected the tracing of the muscle. One factor affecting validity was the exclusion of clear superficial cavities of non-muscle tissue in muscle CSAs, but tracing the CSAs may have included thin layers of superficial fat that were not visually possible to separate from fascial tissue. This may have affected the associations with back function, in particular the associations with body fat since the body fat measurement used in this study takes into account the whole body fat. Also other studies have found either weak or non-existent association between the amount of fat tissue within upper cervical muscles and body composition (Elliott et al. 2005), paraspinal muscles and body composition (Parkkola & Kormano 1992, Wood et al. 1996), and paraspinal muscle atrophy and body weight (Parkkola & Kormano 1992). Also the relative amount of different tissues within the muscles may have affected the associations between muscle composition measurements and back function and body fat. A weak trend was found that for those muscles such as erector muscle including a relatively high amount of intra- and intermuscular non-muscle tissue, the qualitative rating of muscle composition was more strongly (although only moderately) associated with back function and body fat than psoas major and quadratus lumborum muscles which are muscles that contain less intramuscular fat.

It was hoped that it would be possible to improve the between subject comparability by adjusting muscle CSA with its signal intensity adjusted by the signal intensity of the adjacent CSF but this did not have any influence on the associations. The accuracy of the CSF sample was ensured by selecting the CSF sample as close as possible to the disc. The gray zone between the disc and the CSF was separated from the CSF in order to obtain pure CSF and increase the validity of the CSF adjusted muscle. It seems that accuracy of muscle composition measurements of paraspinal muscle fibre areas should be increased by determining more specific measures of the muscle composition (such as isolation of fibrous tissues from superficial fat and from muscle tissue).

6.3 The role of heredity and other constitutional and behavioral factors in back function tests

The role of heredity was substantially different in the three back muscle performance tests. Fifty seven percent of the variance in isokinetic lifting force was accounted for by heredity, but heredity accounted for none of the variance in isometric back extension endurance. Overall, constitutional and behavioral factors appeared to have the greatest influential role on psychophysical lifting capacity and isometric back extension endurance time, explaining 49% to 61% of the variance in test performance. Age explained between 0%-15%, having little or no contribution to the variance in the back tests, similar to other suspected determinants and the results of Gibbons et al. (1997b) for MZ twins, which were a subsample of the present data set.

6.3.1 Contributors in isokinetic lifting performance

Heredity was shown to have an influential role on the isokinetic lifting performance, 41% to 57% compared with 7-15% due to age. This was as expected based on the earlier results that familial aggregation did have a large influence on isokinetic lifting in the MZ twin sample of Gibbons et al. (1997b). Continuing the work of Gibbons et al (1997b) and for the first time including isokinetic lifting performance, the effects of the heredity and shared components of familial aggregation were investigated separately revealing that isokinetic lifting performance is primarily determined by heredity, with common (childhood) exposures and experiences making almost no contribution.

Behavioral and lifestyle factors such as physical activity at leisure time and at work explained 36% of isokinetic lifting force and 44% of isokinetic lifting work does point to possible training effects. Becoming accustomed to work or leisure-time activities requiring maximal effort appears to positively affect the performance in isokinetic lifting which requires maximal effort compared with subjects with no or less experience of physical demands. In addition, maximal lifting performance may be less affected by behavioral or lifestyle factors but more by constitutional factors such as age and anthropometrics. In this study, body weight, lean body mass and the sum of paraspinal muscle CSAs at L3-L4 level explained moderately (15-25%) the variance in the isokinetic lifting performance when heredity was not taken into account. The relatively small proportion of variance explained by anthropometric measures is likely due to the fact that heavier subjects perform worse in dynamic force tests (such as isokinetic lifting) than those who are lighter (Markovic & Jaric 2004) and that anthropometric measures include mutually related components. Also the previous results of no predicting value of anthropometrics for isokinetic performance (Estlander et al. 1994, Keller et al. 1999) support the results of this study.

As indicated by the model taking heredity into account, the combined influence of physical activity parameters was small (17-23%) in isokinetic lifting performance and when the dominant role of age was excluded; physical activity still predicted only 10-11% of the variance. The small role of physical activity and occupational physical loading in isokinetic lifting has previously been shown by Gibbons et al. (1997b) and Malchaire & Masset (1995). One explanation for the weak effect of physical activity parameters would be that some underlying genetic effects exist since both anthropometric measures and physical activity are known to contain a genetic component (Beunen & Thomis 1999, Schousboe et al. 2004).

6.3.2 Contributors to psychophysical lifting capacity

This study showed that heredity and behavioral and lifestyle factors such as physical activity at leisure time and at work accounted almost equally for the variance in psychophysical lifting. However, the proportions of variance of unique behavioral factors explained by specific factors, such as occupational physical loading, participating in aerobic sport, and health, remained low. There appear to be several factors affecting the component of behavioral and lifestyle factors such as physical activity during leisure time and at work, and it is difficult to dissect the separate impact of each variable, especially when these variables seem to be associated. The attempt to further clarify the roles of anthropometric and physical activity during leisure time and at work showed that anthropometric measures and physical activity parameters had a very small (9-15%) predictive value for psychophysical lifting capacity. It seems that the most influential factors related to the psychophysical lifting capacity were not examined in this study. This assumption is based on the reports that submaximal and isometric force levels have been associated with factors such as self-efficacy beliefs (Hazard et al. 1993, Estlander et al. 1994, Malchaire & Masset 1995), sensation of pain (Lethem et al. 1983, Slade et al. 1983, Jörgensen & Nicolaisen 1987, Taimela et al. 1998, Keller et al. 1999), and experience with lifting performance (Lethem et al. 1983, Slade et al. 1983, Crombez et al. 1998). Also psychology and personality have been shown to have an association with lifting force test results (Malchaire & Masset 1995, Lackner & Carosella 1999).

6.3.3 Contributors in isometric back extension endurance

The isometric back extension endurance test is widely used in LBP patients where motivation and pain-related factors are suspected to play an important role in their performance. However, this study was one of the first to seek the reasons why subjects terminate isometric back extension endurance testing (Moreland et al. 1997). The reason was sought by asking at the end of test “Why did you stop the test?” and receiving a variety of reasons. In healthy subjects, Moreland et al. (1997) found that fatigue was the most common reason for terminating the isometric back extension endurance test, which was also the result found in this study. In our 600 subjects, termination due to LBP was rare.

Those having a history of LBP and past LBP periods of higher pain intensity were more likely to interrupt the isometric back extension endurance test due to LBP. This suggests that patients undergoing evaluation and receiving care due to back problems may be even more prone to have their test performance influenced by LBP. The role of LBP was confirmed by the weak trend that fatigue as termination reason decreased and LBP increased when frequency of lifetime LBP was considered. In contrast to these results, one previous study has indicated that those subjects with no LBP tend to stop more often due to LBP (Latimer et al. 1999). Thus, the role of LBP supports an earlier finding that the isometric back extension endurance testing can discriminate between those subjects with and without LBP (Simmonds et al. 1998, Latimer et al. 1999).

In addition to LBP, competitive sport played an influential role as a reason for termination in the isometric back extension test. Fatigue was more likely to be the reason to stop in those individuals with no history of participating in competitive sport suggesting that those subjects with an experience of competitive sport are more accustomed to pushing the limits of their physical capacities to the point through the pain threshold. Individuals with a competitive sport history were able to perform for 14 seconds longer holding time compared to non-sporting individuals. Those stopping due to fatigue exhibited 19 seconds longer holding time than those stopping due to LBP, this representing an expected finding. Based on these results, it seems that for the general adult male population, isometric back extension endurance measures some muscle-related capacity, and pain-related and other behavioral factors (like motivation) play a minor role as reasons for termination.

Heredity had a negligible role in accounting for the variance of isometric back extension endurance. Based on this and earlier studies, it appears that BMI, body weight, physical activity and lifestyle can influence the results of isometric trunk extension force and back extension endurance tests (Jörgensen & Nicolaisen 1987, Holmström et al. 1992, Malchaire & Masset 1995, Barnekow-Bergkvist et al. 1996). However, the result that anthropometric measures and physical activity parameters had a very small predictive value for isometric back extension endurance was unexpected. There may be at least three explanations for this finding. First, the isometric back extension test is a test of holding a position where motivation and pain control may be required to perform well. Secondly, muscles on the back and buttocks are intended to maintain the position of the trunk (Bogduk & Twomey 1991). These muscles may not be as prone to physical activity and exercise as the muscles of the thighs and upper arm (Roth et al. 2001) where the performance is more task related. Thirdly, although some assumptions exists that behavioral factors may play an influential role in isometric back extension endurance (Kankaanpää et al. 1998, Simmonds et al. 1998), few investigators have asked their subjects what was the limiting factor for their test performance (Moreland et al. 1997, Latimer et al. 1999).

7 Main findings and conclusions

7.1 Main findings

Weekly exercise hours and years of participation were the most repeatable of the measured variables (ICC = 0.63-0.90) in the structured lifetime physical activity interview with the 5-year test-retest interval.

The intra-rater repeatability of paraspinal muscle CSAs, quantitative measure and qualitative ratings of muscle composition at L3-L4 level ranged from moderate to excellent (ICC = 0.95-0.99, Kappa = 0.51-0.66). The construct validity of the different quantitative and qualitative tissue measures was low.

For all three back function tests, lean body weight, body weight and sum of the paraspinal muscle CSAs at L3-L4 level predicted 10-25% of variance. The full models of anthropometric measures, paraspinal CSAs and physical activity parameters predicted 7-31% similarly to the most parsimonious models including both anthropometric measures and physical activity parameters.

Genetic effects accounted for most of the variance in the isokinetic lifting force, and to a slightly lesser extent in the isokinetic lifting work and psychophysical lifting capacity, but none of the total variance of isometric back extensor endurance. Correspondingly, in these three tests unique constitutional and behavioral factors accounted for 36%, 44%, 51%, and 61% of the variance, respectively. Age made little or no contribution to back function tests.

In the isometric back extension endurance test, the most common reason for test termination was fatigue. Termination due to LBP was more likely in those individuals with a history of daily LBP and greater pain intensity during the worst back pain episode in the previous 12 months. A longer holding time (19 seconds) was associated with stopping due to fatigue (rather than LBP). Those with a history of participating in competitive sports were more likely to stop due to pain when LBP history was controlled for and had 14 seconds greater holding time than those individuals not participating in competitive sports.

7.2 Conclusions

The investigation of reproducibility and validity of background factors of back function showed that overall reproducibility of lifetime physical activity interview and measures of paraspinal muscles CSAs was acceptable. The structured interview of lifetime exercise suggests that evaluating the mean hours of exercise per week, i.e. combining exercise frequency and session duration, does provide a reasonably repeatable estimate of total lifetime exercise exposure to be used in investigating the effects of exercise. Quantitative and qualitative measurements of the muscle composition of the paraspinal muscles are repeatable tissue measures, but show low associations with body fat and isokinetic lifting performance indicating that measurements of muscle composition have low construct validity.

The roles of heredity and constitutional and behavioral factors on back function test suggest that isokinetic and psychophysical lifting and isometric back extension endurance tests measure very different attributes with different determinants, underlining the importance of careful test selection. The role of heredity was dominant in isokinetic lifting test performance though unique constitutional and behavioral factors did have some effect. This high impact of heredity that the results obtained in the isokinetic lifting test reflect basic physical capacity for lifting. The relatively high impact of heredity also highlights the challenges for potential interventions to alter isokinetic lifting back function. For instance, the anthropometric measures studied here had a weak association with isokinetic lifting performance. Two anthropometric parameters, body weight and lean body mass, were better predictors than paraspinal muscle CSAs.

Psychophysical lifting was affected equally by heredity and behavioral and lifestyle influences. The studied anthropometric measures and physical activity parameters exhibited a weak association with psychophysical lifting capacity, suggesting that other behavioral factors than those considered in this study e.g. lifting experience or self-efficacy beliefs may play a more influential role in psychophysical lifting.

The isometric back extension endurance test was mainly affected by behavioral and lifestyle factors and reflects a muscle-related performance with fatigue representing the predominant reason for test termination. In pain-free subjects, the isometric test reflects back health and performance but in individuals with a significant history of LBP, the test may actually assess back pain. In LBP patients the extent of isometric back extension endurance may be influenced by transient exacerbation of LBP or fear-avoidance. Psychological factors, such as those associated with a competitive type of personality or propensity to motivation, seem to play a role in performance. The results indicate that the reason for test termination could enhance the predictive association of isometric back extension endurance time for future LBP episodes and could be used for screening the effects of rehabilitation or back strengthening because the isometric back extension endurance test is mostly affected by behavioral factors that may well be influenced by appropriate interventions.

TIIVISTELMÄ

Perimä, muut synnynnäiset rakenteelliset tekijät ja käyttäytymistekijät selän toimintakykytesteissä

Tutkimuksen tavoitteena oli selvittää 1) selän toimintakykytesteihin liittyvien tekijöiden luotettavuus, 2) mahdollisuudet havaita muutoksia selkälihaksissa ja 3) perimän, synnynnäisten ja käyttäytymistekijöiden suhteelliset selitysosuudet kolmessa eri selän toimintakykytestissä. Selkälihasten poikkipinta-alat tutkittiin magneettikuvauksella 210 mieheltä, ja mitattiin kehon mittasuhteet ja koostumus sekä isokineettinen ja psykofyysinen nostokyky ja isometrinen selän kestävyystesti 600:lta 35–70-vuotiaalta mieheltä. Strukturoidulla kyselylomakkeella kysyttiin nykyiset ja aiemmat liikunnan harrastukset ja työkuormitus. Elämänaikainen liikuntakysely ja selkälihasten poikkipinta-alojen mittaukset olivat kohtuullisen toistettavia. Kolme tutkittua selän toimintakykytestiä mittaavat hyvin eri ominaisuuksia ja niihin vaikuttivat eri tekijät korostaen testien valinnan tärkeyttä. Isokineettisen nostotestin taustalla oli voimakkaimmin perimä, joten isokineettinen nostotesti kuvastaa hyvin kykyä nostosuoritukseen, joskin mahdollisuudet vaikuttaa isokineettiseen nostovoimaan interventioiden avulla ovat rajalliset. Perimä ja käyttäytymistekijät vaikuttivat yhtä paljon psykofyysiseen nostotestiin. Tutkitut antropometriset tekijät ja liikunnan harrastaminen olivat heikosti yhteydessä psykofyysiseen nostokykyyn, joten oletettavasti muilla kuin tässä tutkimuksessa selvitetyillä käyttäytymistekijöillä on suurempi rooli. Isometrinen selän kestävyystesti kuvasti selän terveyttä ja toimintakykyä, mutta todennäköisesti mittaa kipua tutkittavilla, joilla on pitkä selkäkiputausta. Isometrisen selän kestävyystestin ennustava yhteys mahdollisiin tuleviin selkäkipujaksoihin voisi olla parempi, jos tiedossa olisi testin keskeyttämissyy.

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