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Research article

Assessment of Isometric Trunk Strength – The Relevance of Body Position and Relationship between Planes of Movement

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Abstract
The aim of the study was to assess the differences in maximal isometric trunk extension and flexion strength during standing, sitting and kneeling. Additionally, we were interested in correlations between the maximal strength in sagittal, frontal and transverse plane, measured in the sitting position. Sixty healthy subjects (24 male, 36 female; age 41.3 ± 15.1 yrs; body height 1.70 ± 0.09 m; body mass 72.7 ± 13.3 kg) performed maximal voluntary isometric contractions of the trunk flexor and extensor muscles in standing, sitting and kneeling position. The subjects also performed lateral flexions and rotations in the sitting position. Each task was repeated three times and average of maximal forces was used for data analysis. RANOVA with post-hoc testing was applied to the flexion and extension data. The level of statistical significance was set to $p < 0.05$. Overall, in both genders together, the highest average force for trunk extension was recorded in sitting posture (910.5 ± 271.5 N), followed by kneeling (834.3 ± 242.9 N) and standing (504.0 ± 165.4 N), compared with flexion, where we observed the opposite trend (508.5 ± 213.0 N, 450.9 ± 165.7 N and 443.4 ± 153.1 N, respectively). Post-hoc tests showed significant differences in all extension positions ($p < 0.0001$) and between sitting/standing ($p = 0.018$) and kneeling/standing ($p = 0.033$) flexion exertions. The extension/flexion ratio for sitting was 2.1 ± 0.4, for kneeling 1.9 ± 0.4, followed by standing, where motion forward approximately equals motion backward (1.1 ± 0.6). Trunk sagittal-transverse strength showed the strongest correlation, followed by frontal-transverse and sagittal-frontal plane correlation pairs (R^2 = 0.830, 0.712 and 0.657). The baseline trunk isometric strength data provided by this study should help further strength diagnostics, more precisely, the prevention of low back disorders.

Key words: Voluntary force, testing, hip angle, low back pain.

Introduction

Trunk strength plays an important role from different aspects – related to health and physical performance. Most researchers who compared healthy subjects´ trunk strength in different planes of movement found the greatest strength in sagittal plane extension (Smith et al., 1985), followed by sagittal plane flexion, frontal plane bending (Guzik et al., 1996) and transversal plane rotation with the smallest force output (Beimborn and Morrissey, 1988).

Although maximal voluntary isometric trunk strength is not the best predictor of low back pain (LBP) (McGill, 2007; Lindsay and Horton, 2006), there are studies, which suggest that good global trunk muscle performance may protect back-related problems (Rissanen et al., 2002). When LBP patients and healthy controls were compared, different conclusions have been reported. Kumar et al. (1995) showed that healthy subjects and patients both were stronger in trunk lateral flexion compared with axial rotation, but patients demonstrated just 45% - 55% peak isometric torques of asymptomatic controls. Nouwen et al. (1987) found different muscle activity of abdominal and back muscles during dynamic muscle actions of sagittal flexion only. On the contrary, Ng et al. (2002) found decreased isometric muscle strength in all planes of trunk movement in LBP subjects. Back in 1980 McNeill et al. found a deficit of isometric trunk extensor muscles in LBP subjects, while later studies (Gomez, 1994; Leino et al., 1987) did not confirm the importance of trunk isometric strength as a predictor of low back troubles. Studies on athletes showed similar values during isometric maximal voluntary contractions (MVCs) between asymptomatic subjects and LBP sportsmen. Klein et al. (1991) reported that MVC is a poor indicator of LBP in rowers, Maus et al. (2010) did not find differences in MVC between soccer players and Renkawitz et al. (2006) found similar trunk extension strength in amateur tennis players.

Low fitness level, with not much use of trunk extensors, leads to histomorfologic and structural changes, mainly the atrophy of type 2 muscle fibers. These changes are the causes of decreased strength in these muscles (Parkkola et al., 1993). Dannels et al. (2002) found that healthy subjects had higher activation of multifidus and iliocostalis lumborum during strength training than subacute LBP patients.

Because of different patterns in lumbo-pelvic motion in sagittal plane in LBP subjects (Esola et al., 1996) and significantly higher compression forces on the lumbar spine during axial rotations (McGill, 2007), movements in sagittal and transverse planes are among the most investigated. Data by McGill et al. (2003) suggested that in contrast to a single plane strength analysis, perturbed flexion-extension ratio is related to back problems. McGill (2007) concludes that higher values of trunk extension-flexion strength ratio are more frequently seen in people with LBP. On the other hand, Lee et al. (1999) found greater trunk flexors` strength than trunk extensors` strength in people with back troubles.

While often studied independently, trunk and hip muscles act functionally together. Some studies compared static flexion and extension strength in relation to hip joint position. Keller and Roy (2002) found out higher

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values of extension-flexion ratio with increased hip flexion. Cartas et al. (1993) and Wessel et al. (1994) found a reduced peak isometric trunk flexion torque with increased trunk flexion. Gallagher (1997) showed decreased peak torque of trunk extensors in kneeling compared to standing body position, in contrast with another study (Graves, 1990; Tan et al., 1993), where they found peak torque values of trunk extensors in full hip flexion. Szpala et al. (2011) compared trunk extensor´s torques and spinal muscles activity during sitting and lying body positions. They found significantly higher values of electromyographic activity in m. erector spinae during lying and peak torque values during sitting position. Tan et al. (1993) suggested that increased erector spinae efficiency in more flexed postures during trunk extension tasks is a consequence of its increased mechanical advantage.

Measurement of trunk strength represent an important insight into either the individual`s performance or back health. Although different approaches exist (static, isoinertial, isokinetic), isometric computerized dynamometry offers good reliability (Azghani et al., 2009), relatively cheap testing and a good pelvic fixation. Despite brand and protocol differences between various dynamometers, Demoulin et al. (2012) demonstrated significant inter-system correlations of absolute maximal voluntary contractions values. The aim of this study was to assess trunk flexion and extension strength in different positions of hip joint in sagittal plane. Our second objective was to compare correlations in trunk strength between all three planes of trunk movement in the seated position.

Methods

Subjects

Sixty healthy adults volunteered for the study. The structure of the participants of the study, including age, gender, body mass, and body height is presented in Table 1. Participants with acute or chronic LBP, or systemic neurological disease were excluded. Subjects were informed about the study protocol before the beginning of the experiment and confirmed their voluntary participation by signing the informed consent. The study was approved by the National Medical Ethics Committee.

Table 1. Basic parameters (social and anthropometry) of the subjects.

	Overall	Men	Women
N	60	24	36
Age (years)	41.3 (15.1)	40.5 (14.1	42.1 (16.1)
Body height (m)	1.70 (.09)	1.79 (.07)	1.61 (.12)
Body mass (kg)	72.7 (13.3)	82.6 (13.6)	62.8 (13.0)

Measurement techniques

A multi-purpose dynamometer was custom developed (S2P Ltd., Ljubljana, Slovenia) to measure isometric trunk strength in all three planes of trunk exertion (Figure 1). Maximal force was recorded via force sensor (Z6FC3 – 200 kg, HBM, Darmstadt, Germany), which was traction loaded, depending on movement direction. The signal was 400x amplified, analog-to-digital converted and acquired at a sampling rate of 1000 Hz (NI-USB-6009, NI, Austin, USA). The signals were stored on a personal computer for later analysis. Subjects were instructed to perform three maximal voluntary isometric contractions of trunk flexion and extension in standing, kneeling and sitting position. The order of the tasks was random. Additional testing contains both side bandings and rotations in sitting position. Trunk was maintained in an upright position during the whole testing protocol. A single muscle action gradually increased over ~2 seconds, followed by ~3 seconds of MVC. Rest periods between individual muscle actions were ~15 seconds long, while rest periods between different tests were ~5 min long. All subjects were verbally encouraged to exert their maximal effort. A rigid strap was tightly fastened across the pelvic girdle to achieve good fixation. Another strap was used and placed at chest level to counteract trunk muscle moments in sagittal and frontal planes of movement exertions. To restrain the torque of trunk rotators we moved the strap and placed it across a single shoulder. Knees were fixed on mid tibial level by an adjustable support bar.

Figure 1. Measurement setup for trunk flexion isometric strength testing in standing (A), kneeling (B) and sitting (C) body position. A multi-purpose dynamometer enables measurements in sagittal, frontal and transverse planes. The strap across the pelvis (1) and the knee support bar (2) provide good segmental stability. The height, inclination and horizontal position of the seat (3) could be regulated manually according to subjects` morphological characteristics. Lateral bars with force sensors (4) could be moved vertically and fixed at the appropriate height. A rigid rope connects the belt (at mid sternum level) (5) with the force sensor.

Signal processing and statistical analysis

Custom software (LabView 2011, Austin, USA) was used for signal post-processing. Maximal force was evaluated as the peak value within one second time interval. An average of three repetitions was included into the further statistical analysis. Male and female subjects were analysed together and separately. Repeated-measures ANOVA was used to compare values for each position of flexion and extension movements. Sidak post-hoc test was applied to assess possible statistical differences between the positions. Pearson's correlation was used to study relationship between trunk strength in different planes of movement. The level of statistical significance was set to $p < 0.05$. Statistical analyses were done in SPSS (SPSS statistics 19, IBM, New York, USA).

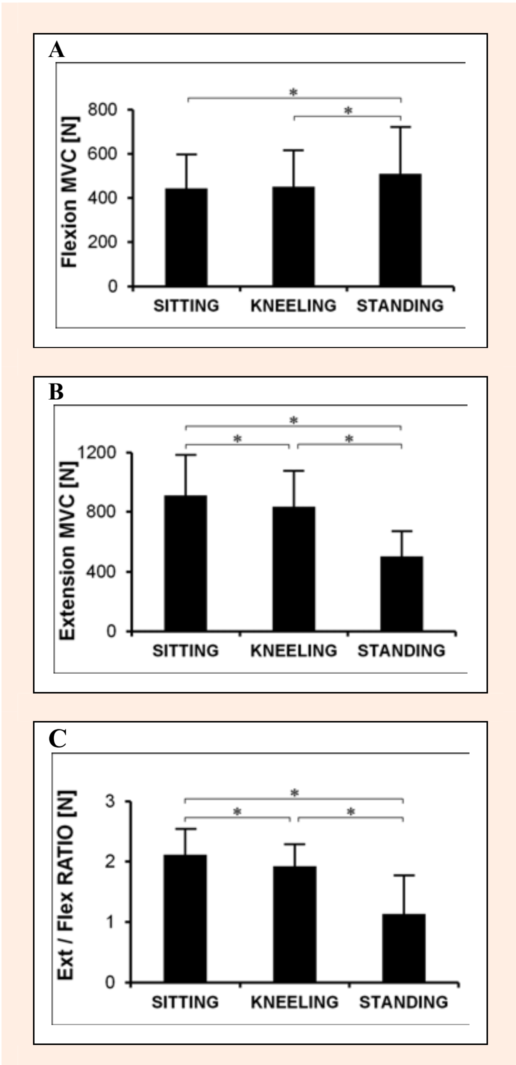

Figure 2. Comparison of trunk flexion (A) and extension (B) force at maximal voluntary contraction (MVC) in different positions of the hip joint in sagittal plane and their force ratio (C). Asterisks represent significant differences between body positions, p < 0.05. Analysis includes both genders.

Results

The effect of body position on the maximal voluntary force developed during static trunk flexion, trunk extension and the ratio between the two is shown in Figure 2. In general, men were stronger than women in all body positions and in both directions (flexion and extension) ($p < 0.05$). The mean relative inter-gender differences, for extension and flexion respectively were: 30.8 % and 34.7 % in sitting, 31.4 % and 38.7 % in kneeling, and 31.0 % and 38.9 % in standing position.

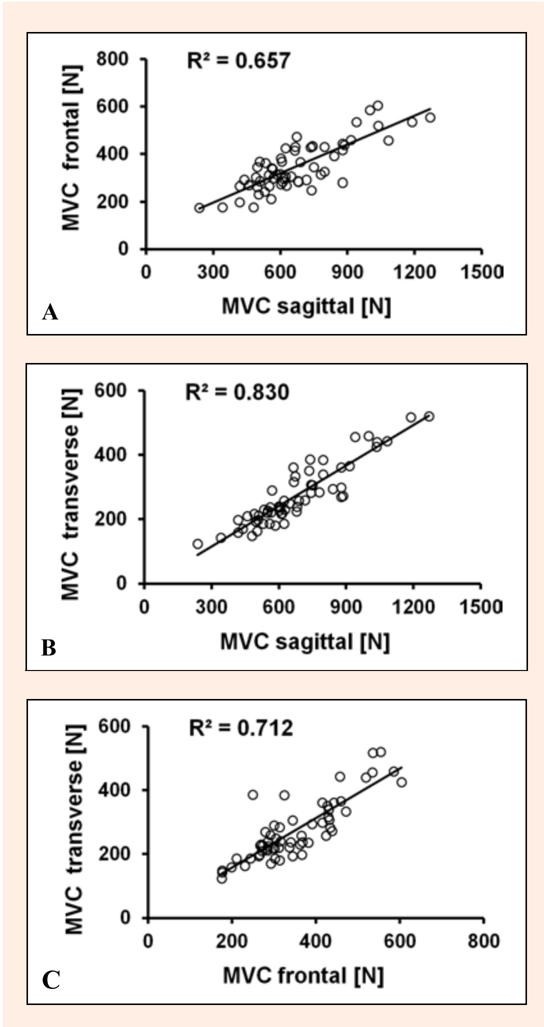

Figure 3. Scatter plots for different pairs of maximal voluntary forces in different directions (i.e. planes of the intended motion). All for the sitting position of testing. In each case the counter-movements were averaged and taken as a representative of the MVC in a certain anatomical plane: sagittal (average of flexion and extension), frontal (average of left and right lateral flexion) and transversal (average of rotation to the left and to the right). Figures A, B and C depict the relationships between the planes of the intended trunk movements (i.e. the corresponding MVCs). Analysis includes both genders.

Overall, regardless of gender, the highest mean force for trunk extension was recorded in sitting posture (910.5 ± 271.5 N), followed by kneeling (834.3 ± 242.9 N) and standing (504.0 ± 165.4 N) ($F = 287.5$, $p < 0.0001$). The opposite trend was observed for trunk flexion (508.5 ± 213.0 N, 450.9 ± 165.7 N and 443.4 ± 153.1 N, for standing, kneeling and sitting, respectively) ($F = 6.8$, $p = 0.006$). In contrast with men, women expressed higher mean maximal force value in sitting than in kneeling flexion exertion.

All three *post hoc* pairwise tests (sitting-kneeling, sitting-standing and kneeling-standing) showed significant differences ($p < 0.0001$) in maximal trunk extension force when we compared all subjects together. Similarly, regarding maximal trunk flexion force, the standing position differed significantly from the other two postures ($p < 0.05$). However, no differences were observed between kneeling and sitting positions.

When male and female subjects were analysed separately, men showed significant difference ($p = 0.040$) only between standing and sitting flexion exertions.

Overall, regardless of gender, the extension/flexion ratio for sitting was 2.1 ± 0.4, for kneeling 1.9 ± 0.4, followed by standing, where motion forward approximately equalled motion backward (1.1 ± 0.6) ($F = 72.2$, $p = 0.000$). *Post hoc* pairwise tests showed significant differences ($p < 0.01$) in the ratios between all three body positions. When *post hoc* tests were carried out separately (men and women), all combinations of MVCs reached statistical significance ($p < 0.01$), except the strength ratio between sitting and kneeling in female subjects ($p = 0.140$).

An assessment of correlations between trunk movements in all three planes is shown in Figure 3. Taking men and women together, trunk strength in sagittal-transverse plane showed the strongest correlation, followed by frontal-transverse and sagittal-frontal plane correlation pairs ($R^2 = 0.830$, 0.712 and 0.657, respectively).

Discussion

Regardless of gender, two main findings were observed in the present study. First, trunk isometric extension strength in sagittal plane increased with increased hip joint flexion. An opposite trend was identified during the same pattern of flexion movement. Second, while testing the relationships of strength between various planes of trunk exertions, we found the strongest correlation between sagittal and transverse plane.

Force assessment on the thoracic level is a result of a complex integration of trunk, pelvic and hip muscles. Psoas muscle originates from the lumbar spine and consequently influences the final torque (from 45° to 60° of hip flexion) output during lower extremity flexion exertion (Yoshio et al., 2002). Despite our effort, we could not reach 100% pelvic fixation, which led to some antero-posterior pelvic tilt during trunk exertions. The initial pelvic rotation and lumbar spine position were different in each subject during sitting, kneeling and standing position. Deviations between the highest and the lowest torque differences during flexion/extension movements might be a result of different hip muscles activity. Differences among the three body positions (sitting, kneeling and standing) were more pronounced for trunk extension (44.7%) than for flexion (12.8%). We suppose that different moment arms and muscle lengths (relative to the length in neutral position) change in accordance to hip positions. In the range of motion between 20° of hip extension and 80° of hip flexion, hamstrings differ greatly in muscle-tendon complex length in comparison with rectus femoris muscle (Visser et al., 1990). Furthermore, psoas muscle has relatively small variations in the moment arm during various positions of hip flexion (Arnold et al., 2000). Long head of biceps femoris, semitendinosus and semimembranosus are all biarticular muscles. Because of that, their maximal torque production is highly dependent on hip and knee joint positions. In our case we observed large angle variations of these joints during different tasks. On the other side, the most powerful hip flexor, the iliopsoas muscle, is monoarticular with less moment arm length variations during various positions of trunk flexion (Carman and Milburn, 2005). The latter fact and iliopsoas´ relatively short length can be associated with reduced force alterations during various hip positions. Due to big differences in the characteristics of the population and methodology used in some studies (Arokoski et al., 2002; Mendis et al., 2010; Reid et al., 1994; Woodley and Mercer, 2005), we speculated that hip flexors have smaller cross-sectional area than hip extensors. The latter could affect overall torque production during trunk flexion tasks. It was interesting that women were stronger in sitting than in kneeling flexion exertion by 1.3 %. On the contrary, male subjects showed higher mean force values in kneeling than in sitting position by 4.2 %.

The strongest torque correlation between sagittal and transverse plane can be associated with similar muscle mass involved during these two movements and more developed intermuscular coordination between these planes. Although, the prime movers during axial rotation are the external and the internal oblique muscles, some degree of rectus abdominis can be detected during trunk rotation. Incorrect trunk action with too much trunk flexion during rotation task might be a reason for an elevated activity of rectus abdominis. In contrast, when movements in frontal and sagittal plane were compared, more force oscillations were observed. Subjects´ ideas of the proper movement performance might have the strongest influence on their trunk lateral flexion performances. In daily life, trunk functional movements are performed mostly in sagittal and transverse plane or they are a combination of both. Because of these reasons, motor programs and associated intermuscular coordination in these planes of trunk exertions are developed the most. Larivière et al. (2009) investigated the influence of visual feedback on the production of the out-of-plane coupled moments during trunk exertions in all three planes. They found visual feedback significantly reduced unwanted moments and altered trunk muscle activation, especially during movements in frontal and transverse planes. The methodology they proposed could have high practical value, although their measurements did not exceed 55% of MVC, because their pilot study showed difficulties of direction maintenance when the force exceeded 60% of MVC.

Granata et al. (2005) measured muscle co-activation during trunk isometric flexion and extension tasks. They found out that flexion exertions produce approximately 50% higher muscle co-activity than back extension during similar moment magnitude. During pushing tasks paraspinal muscles have to provide adequate spine stability. In contrast, when trunk extensors are contracted, they serve the dual role of generating torque and fixing the vertebrae. Thelen et al. (1995) compared muscle co-activation between planes of trunk movement. They found that rotation movements produce three times higher muscle activation of trunk global stabilizators than trunk exertions in sagittal plane. These findings could lead to possible complications during flexion and rotation testing of LPB subjects due to a higher compression load on lumbar spine.

Our study has several limitations which relate to reliability, body fixation and pre-test warm up. In order to learn how to execute the task properly, all subjects in our study performed two submaximal introductory trials directly before each of the test trials. The subjects did not undergo a separate preliminary learning visit, which could have an effect on lower reliability of outcome force values. Even more, Gruther et al. (2009) found a significant learning effect on isometric trunk flexion strength between different testing days in LBP patients. But, in order to minimize bias effect and non-maximal voluntary contractions, we used random order of the tests and applied strong verbal encouragement of the subject. Moreover, pelvic fixation could be problematic in the present study. The amount of tension of the pelvic belt was regulated manually, although always really strongly tightened. Consequently, the subjects could slightly differ in the amount of pelvic tilt and pelvic girdle stabilization during tasks. The same might be true for knee and feet support during trunk lateral flexion, because our dynamometer construction did not allow optimal fixation for lower extremities during frontal plane strength assessment. Although all subjects performed two submaximal contractions of ~50% and ~75% of their MVC in each body position before the measurement, we carried out only a non-standardized warm up, which again might have affected our data in a way of decreased validity.

Conclusion

In this study two main findings were observed. First, trunk isometric extension MVC increased with hip flexion. The opposite was found during the same pattern of trunk flexion (both genders together and men only) except for women, who showed higher forces outcomes during sitting than during kneeling. Second, the strongest correlation was found between sagittal and transverse plane. In order to increase reliability, future strength testing should provide an adequate warm-up protocol, initial familiarization with the equipment and good pelvic fixation. The data provided by this study should help further strength diagnostics of the trunk, especially in the context of preventing and curing of low back troubles.

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Key points

- Maximal voluntary isometric force of the trunk extensors increased with the angle at the hips (highest in sitting, medium in kneeling and lowest in upright standing).
- The opposite trend was true for isometric MVC force of trunk flexors (both genders together and men only).
- In the sitting position, the strongest correlation between MVC forces was found between sagittal (average flexion/extension) and transverse plane (average left/right rotation).
- In order to increase the validity of trunk strength testing the letter should include: specific warm-up, good pelvic fixation and visual feedback.

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