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Main force directions of trunk muscles: A pilot study in healthy male subjects

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ABSTRACT

Muscles work most effectively along their anatomically defined action vector(s) which has implications in training and therapeutics. Action vectors can easily be identified in extremity muscles and smaller muscles of the trunk, but are less clear in larger trunk muscles. Trunk muscle exercises and diagnostics have traditionally relied on tasks in the sagittal plane – a practice that is being reconsidered. Therefore, this study aimed at identifying main force directions (MFDs) of major trunk muscles expressed in terms of deviation from the sagittal plane. 20 healthy male subjects underwent graded isometric submaximal static load applications on their trunk by application of simultaneous and incremental tilting and rotating from vertical to horizontal at rotational angles of 45° starting from 0° (forward tilting) around 360° with only the lower body secured. Surface EMG (SEMG) from six trunk muscles on each body side was recorded. The MFD of each trunk muscle was estimated by considering SEMG amplitudes of all rotational angles, separately for all tilt angles, and was expressed as angular deviation from sagittal plane. The calculated MFDs of trunk muscles deviated from sagittal plane to differing extents. Mean MFD angle was smallest (more parallel to sagittal plane) for rectus abdominis muscle (±14°), becoming more lateral for external oblique (OE, ±32°) and internal oblique abdominal muscles (OI, ±47°). As tilt angle increased, MFD angles increased for OE, but decreased for OI. Iliocostalis muscle showed an almost laterally directed MFD with systematic dependency on body side (−90° for left and +75° for right side). Both paravertebral muscles (longissimus and multifidus muscles) showed almost identical MFD angles of about ±145° and varied the least with tilt angle. All trunk muscles' MFDs deviate from sagittal plane and, in addition to flexing and extending, have both bending and/or rotational capabilities. MFDs of oblique abdominal muscles are systematically altered by tilt angle in accordance with their more divergent fiber directionality. The results provide a basis for specifically targeted diagnostics and training of trunk muscles.

1. Introduction

Muscular force is most effective along the main force vector of a muscle, muscle part, or muscle group. These vectors are defined as the main force directions and are described in relation to body perspective. For most muscles, main force directions (MFDs) are defined anatomically by fiber direction, anatomical location, and insertion points of the respective muscles (Gray, 1942; Kendall,

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Kendall Mc Geary, Provance, Rodgers, & Romani, 2005), best seen in the extremity muscles and smaller muscles of the trunk as they have clearly localized insertion spots. In the case of the larger muscles of the trunk and especially abdominal trunk muscles, the MFD picture becomes less clear because these muscles have multiple insertions that may span over large distances as well as divergent fiber directions. Because of this, their mechanical action cannot be defined as accurately through an anatomical study (Gray, 1942; Kendall et al., 2005). Correspondingly, large trunk muscles are also activated less predictably in terms of a main direction, dependent upon load level and angle, which could have implications therapeutically and diagnostically. Strengthening and therapeutic exercises for the trunk have traditionally focused on tasks in sagittal and / or frontal plane, a practice that precludes more global tasks to improve muscle coordination and provide better spinal support (Ekstrom, Donatelli, & Carp, 2007; Willett, Hyde, Uhrlaub, Wendel, & Karst, 2001). New methodological approaches and normative data are needed to experiment in the development of functionally more adequate improvements of diagnostic methods and biofeedback control.

To get a better picture of how the trunk muscles manipulate and support the spine, extensive work has been done, starting in the late 1950's and still continuing to date, aimed at quantifying trunk muscle's effort during specific tasks (Bressel, Dolny, & Gibbons, 2011; Godfrey, Kindig, & Windell, 1977; Guimaraes, Vaz, De Campos, & Marantes, 1991; Juker, McGill, Kropf, & Steffen, 1998; Lipetz & Gutin, 1970; Noble, 1981; Walters & Partridge, 1957; Willett et al., 2001), or – the other way around – to identify tasks that activate the respective muscles most effectively (Shamsi, Sarrafzadeh, Jamshidi, Zarabi, & Pourahmadi, 2016). Several studies have already tried to systematically examine trunk muscle function with respect to activation characteristics by applying specifically directed force vectors on the trunk (Lavender, Tsuang, Andersson, Hafezi, & Shin, 1992; Perez & Nussbaum, 2002). These latter investigations aimed at the identification of co-contraction characteristics of trunk muscles when force vectors were altered systematically during bending to the side and twisting. However, the individual action vectors of trunk muscles were not yet examined during loading from different angles.

The aim of our study was therefore to add to the existing knowledge of large trunk muscle activation by determination of main force directions using surface EMG: we precisely defined MFDs by using surface EMG signals measured at the SENIAM recommended spots (Hermens et al., 1999; Ng, Kippers, & Richardson, 1998; SENIAM) of individual trunk muscles during static loading at different angles. In addition we asked, if MFD directions were influenced by load level and body side. To this end we applied graded isometric submaximal forces on the trunk in transversal plane by both tilting and rotating the trunk, held erect with lower body fixed. Increased understanding of the most effective force direction of trunk muscles could inform general training methods, functional diagnostics, and targeted rehabilitation approaches.

2. Methods

For this study 22 healthy male subjects from the university campus were recruited (subject data are given in Table 1). They underwent a brief clinical examination and were questioned about their medical history to exclude possible relevant orthopedic pathologies like chronic or acute back pain, past injuries or surgeries of the spine. Two subjects had to be excluded. As part of a larger study, ethical approval from the local ethics committee was given (0558-11/00). Every participant was informed prior to the study and gave his written informed consent. As a first fundamental approach, this investigation was conducted on slender healthy male subjects to avoid sex-related and adipose related variations.

2.1. Device

The investigation was performed in a computerized test and training device (CTT Centaur, BfMC, Germany) enabling the application of graded forces on the trunk by incrementally tilting the person to horizontal position (Fig. 1). In addition to whole body tilt in sagittal plane, the device can rotate, enabling application of lateral force vectors. This meant that the load applications had both a horizontal and a vertical component: A certain "tilt angle" imposes a specific angle (degrees) as a measure of load (i.e. moment along the gravitational field). The term "rotation angle" describes the load vectors' directionality in three-dimensional space.

In the device, the person's lower body was fixed while the upper body above the iliac crest maintained its freedom of movement. Subjects, while positioned in the device, had to counteract simultaneous tilt and rotation angles, during which their only task was to maintain erect body position. The device was equipped with an open harness positioned over the subject's shoulders. Strain gauges together with a crosshair display, visible to the subjects, provided biofeedback to ensure erect body position: as long as the biofeedback display's control point remained in the center of the crosshair no force was being applied to the harness and erect body position was achieved and maintained.

2.2. Procedure

Subjects were tilted to tilt angles of 5°, 10°, 20°, 30°, 45°, 60°, and 90° that are equal to portions of their upper body weight of 9%,

Table 1
Subject data (mean values ± SD).

Age [years]	Weight [kg]	Height [cm]	BMI [kg/m^2]
36.0 ± 7.5	75.1 ± 8.3	180 ± 5.9	23.1 ± 1.9