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Activation of transversus abdominis varies with postural demand in standing

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ABSTRACT

Transversus abdominis (TrA) is a multifunctional muscle, being involved in pressure regulation within the abdominal cavity and thereby in direction independent stabilization of the spine and resistance to imposed trunk flexion moments. Indirect evidence suggests a role of TrA also in postural control of the erect human trunk. The main purpose here was to investigate if the magnitude of TrA activation is related to postural demand. Eleven healthy males performed seven different symmetrical static bilateral arm positions holding 3 kg in each hand. The arm positions were selected to systematically vary the height of the centre of mass (COM) keeping imposed moments constant and vice versa. EMG was recorded bilaterally with fine-wire intramuscular electrodes from TrA and obliquus internus (OI) and with surface electrodes from rectus abdominis (RA) and erector spinae (ES). Intra-abdominal pressure (IAP) was measured via a pressure transducer in the gastric ventricle. TrA was the only muscle that displayed activation co-varying with the vertical position of the COM. Further, TrA activation increased, together with IAP and ES activation, with imposed flexion moment, i.e. with arms extended horizontally forward. In contrast to OI, RA and ES, TrA activation was independent of the direction of the imposed moment (arms held inclined forward or backward). In conclusion, TrA activation level is uniquely associated with increased postural demand caused by elevated COM. Also, TrA appears to assist in counteracting trunk flexion via increased IAP, and contribute to general spine stabilization when the trunk is exposed to moderate flexion and extension moments.

1. Introduction

Coordinated activation of the trunk muscles is essential for spine stabilization [1,2]. In a static upright posture the objective of the motor control system is to ensure sufficient spinal stability to keep the trunk in erect equilibrium [3]. This control is challenged by changes in postural demand, e.g. by varying the size of the support area or the height of the centre of mass (COM), i.e. altering the impact that any destabilizing moment would have.

The spine is surrounded by a complex of muscles with different geometries, force capabilities and lines of action. The contribution of each muscle to ensure sufficient spinal stability is likely to be task dependent [4]. However, special interest has been devoted to the innermost abdominal muscle, transversus abdominis, TrA [5]. TrA has a transverse fibre direction forming a wide "belt" around the ventro-lateral side of the abdomen. Its mechanical role is believed to be to contribute to vertebral alignment during imposed moments on the trunk, executed mainly via either regulating the intra-abdominal pressure (IAP) [6] and/or transmitting force to the spine via its attachment to the thoraco-lumbar fascia [7]. In addition to its alleged involvement in general spine stabilization, TrA has other functions, e.g. contributing to breathing [8], and possibly also taking part in direct control of trunk movements [6].

There is also indirect evidence for TrA participating in postural control with the activation being affected by different loading modalities in various body positions. Primarily the timing of TrA activation onset has been investigated, showing an early activation of TrA relative to more superficial trunk muscles during rapid arm movements [9]. A delayed activation is present when the postural demand decreases as seen in sitting with a back support compared to upright standing [10] and in side-lying [11] compared to standing [12]. However, also the magnitude of activation seems to be affected by changes in postural demand with a direction non-specific level of activation in the sagittal plane in side-lying [11] as opposed to upright stance, where increased activation of TrA was observed in ventral compared to dorsal loading [12].

Thus, although there are results indicating an influence of postural demand on TrA activation, a coherent understanding of this association is lacking. Mainly, differences in loading modalities and in body positions between and within studies, make it difficult to distinguish the effect of postural demand as such from other

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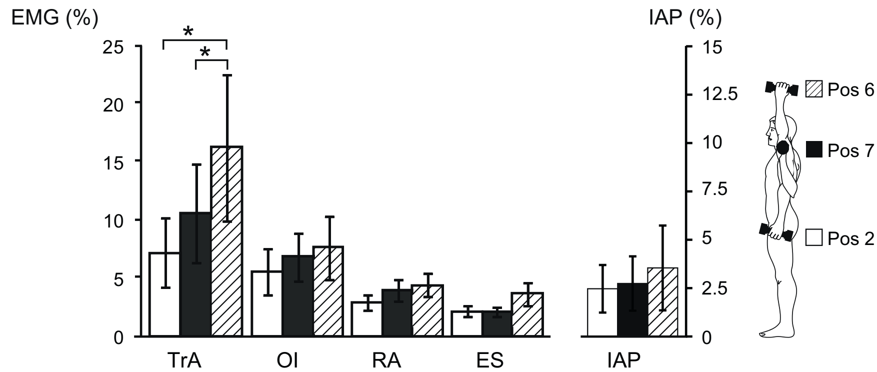

Fig. 1. Mean relative EMG and IAP amplitudes with 95% CI for comparisons between positions 2, 7 and 6 with varying height of COM and minimal imposed moment (* indicates $p < 0.05$).

possible sources of variation, such as differences in imposed moments. In the current series of experiments, we attempt to differentiate between the two by manipulating the COM of the body vertically and/or horizontally by assuming different loaded arm positions in standing. Our main hypotheses were that TrA activation would (1) increase with height of COM, (2) be independent of the direction of imposed moment, and (3) increase with imposed flexion moment on the trunk.

2. Methods

2.1. Subjects

Eleven healthy male volunteers participated (mean ±1 SD age 28 ± 4 years, height 1.81 ± 0.08 m, mass 80 ± 8.4 kg). Inclusion required that the subjects had not experienced any low back pain in the last 3 years, had no muscular-, skeletal-, neurological- or inflammatory disease and had not had any surgery on the trunk. All subjects read and signed a written consent form prior to participation in the study. The protocol was approved by the Regional Ethics Committee.

2.2. Experimental procedure

The subject stood barefoot on the floor and held a 3 kg dumbbell in each hand. The task was to hold both arms symmetrically, in different static positions that were designed to systematically alter the height of the COM of the body and/or the moment imposed on the trunk. There were seven different positions (Figs. 1–4), the order of which was randomized between subjects. Each position was held for 7 s in three consecutive trials. Intra-class correlation (ICC) coefficients between the three trials for all four muscles and seven positions ranged 0.578–0.994 (median 0.935).

All seven positions were initiated from a start position of quiet standing with arms along the sides. During sampling, the subject was instructed to keep his eyes on a picture of the current target position placed at eye level in front of him. On a verbal command the subject raised his arms from the start position to the required target position. When the subject held the correct position steadily, judged by visual appearance, the investigator pressed a trigger marking the time in the sampling data file. After 7 s the subject got a verbal command and lowered his arms back to his sides.

2.3. EMG and pressure measurements

Bilateral intra-muscular EMG was recorded with fine-wire electrodes from transversus abdominis (TrA), insertion point in the mid-axillary line, 2 cm caudal to the twelfth rib, and obliquus internus (OI), insertion point 2 cm ventral of the mid-axillary line and 2 cm caudal to the twelfth rib. The electrodes were made of Teflon coated seven-stranded silver wire (0.4 mm in diameter, Leico Industries, USA) with 2 mm of the coating removed at the tip. Each wire was inserted using sterilized needles (0.70 mm × 88 mm for TrA and 0.60 mm × 60 mm for OI) under ultrasound guidance (GE Logic 9, Transducer 12 MHz, UK). The tips for bipolar recordings were placed with an interelectrode distance of about 5 mm. Needles were inserted obliquely from the side to minimize the risk that internal muscle movements would pull out the electrode. After electrode placement, the needles were gently removed. Bilateral surface EMG recordings were made from rectus abdominis (RA), 2 cm lateral to the umbilicus, and erector spinae (ES), 3 cm lateral to the L3 spinous process. Measurements were made with Ag/AgCl electrodes (Blue Sensor, Ambu, Denmark) placed with an interelectrode distance of 2 cm. All EMG signals were amplified 1000 times (Myosystem 2000, Noraxon, USA) and band-pass filtered between 10 and 1000 Hz (Neurolog filters, Digitimer Ltd., UK) with a notch filter at 50 Hz.

Intra-abdominal pressure (IAP) was recorded with a pressure transducer (Gaeltec, UK) placed in the gastric ventricle with a naso-gastric catheter [13]; signals were amplified 1000 times (custom made amplifier, Digitimer Ltd., UK). The lowest individual IAP value collected in the quiet standing position was set to 0 for each subject. IAP data from two subjects had to be discarded due to technical reasons. The invasive procedures caused minimal pain and discomfort. All EMG and IAP signals were analogue-to-digital converted at a sampling rate of 2 kHz and collected with computer software (Spike2 5.15, Cambridge Electronic Design, UK).

2.4. Data analysis

All EMG amplitude values were calculated as root mean square (RMS) for the 5 s interval immediately following the trigger signal. EMG amplitudes were normalized to the highest EMG RMS value obtained for each muscle during maximum voluntary contractions in upright standing (MVC). This value was determined with a 1 s sliding window across three static maximum efforts: attempted trunk flexion, Valsalva manæuvre (maximal voluntary pressurization of the abdomen) with a superimposed attempted trunk flexion, and attempted trunk extension. All MVCs were performed twice. For IAP, values were calculated and reported as means

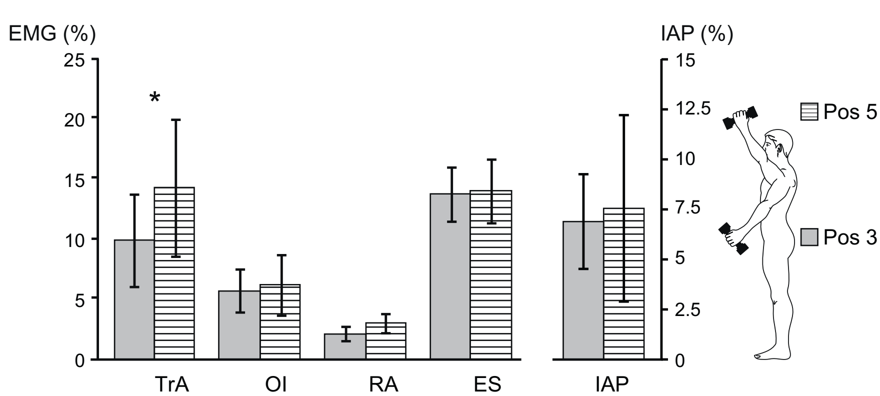

Fig. 2. Mean relative EMG and IAP amplitudes with 95% CI for comparison between positions 3 and 5 with varying height of COM and a constant imposed flexion moment (* indicates $p < 0.05$).