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Trunk muscle amplitude-force relationship is only quantitatively influenced by control strategy

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ABSTRACT

The Surface EMG (SEMG) amplitude-force relationship of trunk muscles has been shown to be non-linear for the abdominal muscles and linear for the back muscles. Recent studies could prove that abdominal muscles' stress level is influenced by control strategy with higher amplitude levels when the trunk posture has to be maintained along its body axis at defined submaximal force levels (posture-controlled), meanwhile compensating corresponding force levels against a fixed resistance point (force-controlled) in upright position caused inferior amplitude alterations. We wanted to check if the different control strategies alter the amplitude–force relationship of trunk muscles quantitatively and/or qualitatively. In this study 39 healthy subjects of both sexes were investigated while being isometrically exposed to defined submaximal flexion and extension forces on their trunk. The forces were generated by applying real (posture-controlled) and simulated (force-controlled) tilt angles on the trunk. SEMG was taken from five trunk muscles and normalized according to the amplitude during maximum voluntary contractions (MVC normalized), and to the occurring maximum value during every force direction and strategy, respectively (maximum normalized). The MVC normalized amplitudes were always greater for the posture-controlled situations for all abdominal muscles, independent of sex, but were not affected at all for the back muscles. The maximum normalized amplitudes of all trunk muscles were not systematically influenced by the applied control strategy. Therefore, the amplitude–force relationship of trunk muscles is muscle and exercise type-specific: for the abdominal muscles the amplitude-force relationship is quantitatively altered by control strategy.

1. Introduction

The Surface EMG (SEMG) amplitude–force relationship of trunk muscles is localization specific: Abdominal muscles are characterized by a non-linear relationship while the back muscles show a linear behavior (Anders et al., 2008). These results were established during whole body tilts: subjects stabilized their upper body against the force of their upper body weight (UBW) administered at different tilt angles, while remaining in an upright position.

Recent findings show that in both sexes abdominal muscles reach considerably elevated SEMG amplitude levels relative to expected stress levels during isometric flexion induced by 90° backward tilt (Huebner et al., 2015). In women these levels exceeded even those observed during maximum voluntary contractions (MVC) and differed significantly from those found in males. This matches with the well-known differences in trunk muscle force capacities between sexes (Keller and Roy, 2002).

In contrast, back muscles' activation levels showed linear characteristics (Huebner et al., 2015). For the multifidus muscle the measured values almost perfectly complied with linearly estimated ones. Concerning the longissimus increasing load even provoked SEMG values which were systematically lower than the estimated ones (Huebner et al., 2015).

These new results disagree with the earlier findings by Marras et al. (Marras and Davis, 2001) who discovered an almost perfect linear amplitude-force relationship for all trunk muscles. However, the results of Marras et al. (Marras and Davis, 2001) were obtained during graded submaximal force-controlled isometric contractions. Therefore, a remarkable difference between the two experimental setups was the load application condition.

As a result the question arose whether and, if so, to what extent the motor control strategy could have an influence on the respective amplitude–force relationship. Consequently, we conducted further experiments, studying the influence of two different load application regimes: force-control and posture-control.

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Under the force-controlled condition subjects applied defined portions of their upper body weight (UBW) against a fixed resistance whereas the posture-controlled situation required the compensation of corresponding portions of the UBW by graded whole body tilts. The most striking result we discovered at first was that only the abdominal muscles' amplitudes were found to be influenced by control strategies; meanwhile control strategies had no effect on the back muscles' amplitudes (Hansen and Anders, 2014).

Posture-controlled tasks required the abdominal muscles to expend up to a 1.5 fold greater effort compared to force-controlled conditions. This was independent from load level.

The inevitable question, deriving from these findings was, whether the different control strategies influence the shape of the amplitude–force relationship of trunk muscles or if the observed differences are of quantitative nature. This could have clinical implications since in daily life we almost permanently have to control our trunk position in order to maintain proper vertebral alignment. The abandonment of the respective equilibrium is known to be associated with the development of back pain (Panjabi, 1992, 2003). Down to the present almost all trunk muscle function tests aim at the determination of maximum force capacities which are mostly determined during isometric, force-controlled situations. Consequently, if quantitative and or qualitative differences between posture- and force-controlled load situations are to be considered these test concepts would have to be questioned.

Further, since sexual dimorphism in humans is largely developed (Kirchengast, 2014) and is most prominent in the musculoskeletal system (Frontera et al., 1991) it has impact on trunk muscle co-ordination during several tasks (Anders et al., 2007; Anders et al., 2009; Bouillon et al., 2012; Marras et al., 2002; Miller et al., 2010). Therefore, we also investigated the influence of sex on our measurement results.

2. Methods

39 subjects (19 women and 20 men) were enrolled for the study (subject data see Table 1). The subjects were clinically healthy in terms of their medical histories and cardiopulmonary statuses, and had no prior injury to the musculoskeletal system. Participation was voluntary. Informed written consent was obtained from each volunteer. As part of a larger study the actual study was approved by the local ethics committee of the Jena University (3021-01/11) and therefore complies with international ethical standards.

2.1. Device

The tests were performed in a computerized testing and training device (CTT CENTAUR BfmC, Germany). The lower body up to the pelvis is immobilized, while the upper body remains free (Fig. 1). This multi-functional device applies graded forces to the trunk by tilting the subject at defined angles up to a horizontal position. Because full mobility of the upper body is given, stabilization will occur along the longitudinal axis of the body. To check on the exact adherence of upright body position during tilt, the training device is equipped with an adjustable open harness situated at the subject's shoulder level. It contains strain gauges and is connected to a biofeedback monitor located in front of the subject that enables control of exact body position: As long as the subject remains in a neutrally aligned position the control point on the display of the posture biofeedback monitor remains in the center of a crosshair.

Regarding the current investigation, an additional monitor was provided, forming yet another biofeedback system in order to supervise the force-controlled tasks. Defined offsets from the zero baseline were set on the force biofeedback monitor and therefore displayed a proportionally deviated control point that had to be brought back to zero by the subject applying the respective forces to the harness.

The tasks were performed in sagittal plane and contained realized and simulated forward and backward directed tilt angles of 5°, 10°, 20°, 30°, 45°, 60°,and 90°.

Fig. 1. Subject performing a 45° backward tilt (posture-controlled condition).

Table 1
Subject characteristics.

	Age [years]	Weight [kg]	Height [cm]	BMI [kg/m^2]	UBW [N]	MVC/UBW extension	MVC/UBW flexion
Women							
Median	24.0	60.5	170.0	21.4	231.0	2.3	1.4
upper quartile	1.0	3.8	3.0	1.1	6.5	0.0	0.2
lower quartile	1.0	2.5	2.0	0.7	8.0	0.3	0.1
Mean	23.9	61.9	168.9	21.7	230.6	2.2	1.5
SD	1.8	7.1	8.3	1.7	17.9	0.3	0.2
Men							
Median	25.5	72.9	180.0	22.6	302.0	2.5	1.9
upper quartile	2.8	3.3	1.3	1.4	21.5	0.2	0.2
lower quartile	1.8	5.5	5.3	0.9	12.8	0.2	0.1
Mean	27.4	72.1	178.7	22.6	303.6	2.6	2.0
SD	7.0	5.8	6.2	1.6	27.2	0.4	0.4
***t*-test**	0.048	< 0.001	< 0.001	0.094	< 0.001	0.002	< 0.001

Abbreviations: UBW: Upper body weight; MVC: Maximum voluntary contraction force.

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