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Intra-Abdominal Pressure and Activation of Abdominal Muscles in Highly Trained Participants During Sudden Heavy Trunk Loadings

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Study Design. Ten participants were exposed to heavy sudden trunk loads as they might occur during patient handling.

Objectives. The aim was to observe if well-trained men and women use their full rate of intra-abdominal pressure (IAP) development when exposed to heavy sudden trunk loads. Further, to elucidate to what degree the rectus abdominus muscle is activated when the IAP is developed.

Summary of Background Data. Well-trained judo fighters are used to heavy sudden trunk loads and can produce a high IAP. It is unknown whether they use their full potential. IAP can increase the spinal stability and has been suggested to unload the spine. The unloading effect will, however, disappear if the development of the IAP demands substantial activity in the vertical fibers of the abdominal muscles.

Methods. Five male and five female well-trained judo and jujitsu fighters were exposed to heavy sudden trunk loadings through imitated patient handling situations where the patient fell and the fighters should hold the patient and prevent the fall. IAP was measured with a catheter in the stomach. Along with the IAP measurement, EMG was measured on the abdominal muscles, and the load on the low back was quantified by a three-dimensional dynamic biomechanical calculation of the torques at the L4–L5 joint.

Results. The well-trained judo fighters did not use their full potential of the IAP development when exposed to the heavy sudden trunk loads, but the women had to use a higher level of their IAP and extension torque capacity to comply with the heavy loads. The rectus abdominus muscle does not contribute to the IAP development when the trunk is exposed to a sudden heavy load.

Key words: intra-abdominal pressure, electromyography, sudden trunk loading, biomechanical model, low back muscles. **Spine 2004;29:2445–2451**

Low back injuries are frequently observed among employees in the healthcare sector.[1] In Denmark, the majority of nurses and nurses' assistants are women. The functional physical capacity of the trunk muscles is different between the two genders. While women are reported to have equal or increased endurance in back-muscles compared with men at the same relative load,[2] men are generally stronger than women. The high risk of low back disorders found in nursing personnel has, among other risk factors, been associated with patient handling,[3,4] and patient handling may cause sudden unexpected loading of the trunk.[5] Active structures acting on the spine to produce stiffness and stability are important to avoid injury. Cholewicki and McGill[6] reported that even small loads in a momentary loss of stability could lead to unexpected displacement in the spine and thus result in injury. Increased muscle activity and/or an increase in intra-abdominal pressure (IAP) can increase the spinal stability.[7–10] For the muscle activity, gender differences in preparatory coactivation have been reported in relation to sudden light trunk loadings.[11] IAP in both men and women has been shown to increase rapidly during heavy sudden trunk loading.[12] IAP is primarily produced by m. transversus abdominus (TA), and training of the abdominal muscles has shown to increase the rate of IAP development, but not the maximal IAP during Valsalva maneuver.[13] It is known that men compared with women can produce a higher maximal IAP, but it is not known whether men ever use their higher potential or whether their rate of IAP development is higher. If the IAP plays a significant role in spinal stability, the rate of the IAP development is important when the spine is suddenly exposed to a heavy load.

Modeling[14,15] as well as direct measurements[16] have demonstrated that increased IAP can have a mechanical function on the spine in adding an extension torque, especially in sagittal loading. The critical element is to what extent the development of IAP is caused by activity in abdominal muscle fibers that produce a counteracting torque. Especially the m. rectus abdominus (RA) produces a trunk flexion torque when activated. In situations where persons have to hold or grip something in front of them, it would not be beneficial to add a flexion torque.

The IAP is often investigated by using the Valsalva maneuver, and when a high IAP is developed through this maneuver, all the abdominal muscles including the RA are involved.[17] The muscle activation pattern seen during the Valsalva maneuver may, however, not express the activation pattern during heavy sudden trunk loading where IAP is produced. Studies on postural stability

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have suggested that TA may be controlled independently of the other muscles in the abdominal wall.[18]

Our aim was to see if well-trained men and women use their full rate of IAP development when exposed to heavy sudden trunk loads and, further, to elucidate to what degree the RA is activated when IAP is developed.

■ Materials and Methods

Methods

Participants. Five female (age, 23 ± 2.6 years; height, 1.68 ± 0.04 m; weight, 65 ± 5.0 kg) and five male (age, 28 ± 6.9 years; height, 1.79 ± 0.1 m; weight, 79 ± 15.1 kg) (mean ± SD) well-trained judo or jujitsu fighters participated in the study. In judo and jujitsu, the fighters are used to carry the weight of their opponent while their own body is in an awkward position. They also throw each other in situations where the spine is both flexed and rotated, and according to the literature, back problems are not an important problem for active judo and jujitsu fighters.[19] We chose this group of participants in order to be able to apply heavy sudden trunk loads without injuring the participants. Participants were excluded if considerable pain in the back or the neck was experienced on the day of the tests, or in the presence of high blood pressure, pregnancy, angina pectoris, previous prolapsed intervertebral disc, or the use of heart/lung medicine. None was excluded. The study was approved by the Local Ethical Committee reference no. (KF) 01–237/00 and (KF) 01–213/01.

Procedure. After placement of the IAP catheter and the EMG electrodes, reference contractions were made. Reference contractions EMG: MVC tests for the trunk muscles were made according to Essendrop *et al*[20] and McGill[21] to measure the maximal isometric extension and flexion torque and to measure the maximal EMG activity of relevant muscles.

Reference Contractions IAP. Maximal IAP was obtained from three maximal Valsalva maneuvers. Before these measurements, the participants submaximally increased their IAP several times to familiarize with IAP development. Biofeedback was given on a screen. The participants were asked to increase the pressure from zero to maximal in 2 seconds, then maintain the maximal pressure for a few seconds, and finally relax. After an additional pause, the participants were asked to make the IAP curve as steep as possible, and they familiarized themselves again through use of biofeedback. Two Valsalva maneuvers were performed aiming the maximal rate of IAP development.

Trials of Loading. The participants then carried out a standard lift by lifting a 15-kg load. The handles were placed 0.85 m above the floor. The participant started standing upright, then inclined forward and picked up the box and returned to upright standing where the box was held for 1 second with 0° of flexion in the shoulder and 90° of flexion in the elbow. Then the box was placed on the floor again. The lift was symmetrical with a horizontal distance of 0.4 m from the toes to the center of the box.

In the laboratory, the participant then performed parts of imitated patient handling trials. During the patient handling, the patient occasionally fell and the participant was to support the patient and prevent the fall. In all trials, the participant had a grip on the patient with both hands. The person acting as a patient was a healthy male (M.E., weight 75 kg, height 1.78 m, age 33 years). In seven trials, the patient was continuously moving slowly up and down on the knees. The participant followed the movements of the patient, and the patient did not fall the first time this situation was performed. Thereafter the patient either fell at a nonspecific moment in the movement or fell immediately. The trial without a fall served as a control trial for the fall trials. The seven trials were not performed in a row. Three other patient handling trials were performed in between the seven trials to give variety and improving the possibility of the imitated patient in tricking the participant.

Measurements. The catheter measuring the IAP (Medtronic Single Sensor Micro Transducer Catheter, Medtronic Inc, Skovlunde, Denmark) was inserted directly through the nose; the length to the ventricle was measured beforehand. After insertion, the placement of the catheter was checked in relation to the diaphragm by visual check of the pressure curves during normal breathing.

As a measure of muscle activity, EMG was obtained from surface recordings. EMG was recorded from the m. obliquus externus (OE), m. obliquus internus (OI), RA, and finally a broad site (Broad) aimed to measure activity from the oblique muscles along with activity from the TA.[22] Pregelled Ag/AgCl surface electrodes (720–01-k Medicotest A/S Denmark) were used. The interelectrode distance was 3 cm except for the RA (2 cm) and the broad recording site (5 cm). The electrodes on the RA were placed approximately 2.5 cm lateral of the umbilicus, on the OE between the anterior superior iliac spine (ASIS) and the caudal border of the ribcage angled 45°, and on the OI at the midpoint between the ASIS and the pubis symphysis angled at 10°.[23] The broad site was placed with the medial electrode placed midway between the ASIS and the caudal border of the ribcage, the second electrode being placed 5 cm posteriorly along the horizontal muscle fibers.[22]

The EMG signals were preamplified, low-pass filtered at 450 Hz, and sampled with a frequency of 1000 Hz. The data were high-pass filtered with a cutoff frequency of 10 Hz, rectified, and low-pass filtered with a second order single-pass Butterworth filter, having a cutoff frequency of 2.5 Hz. Finally, the EMG was normalized to the maximum value obtained from the MVC tests.

The load on the low back during the patient falls was quantified by biomechanical calculation of the torque and compres-

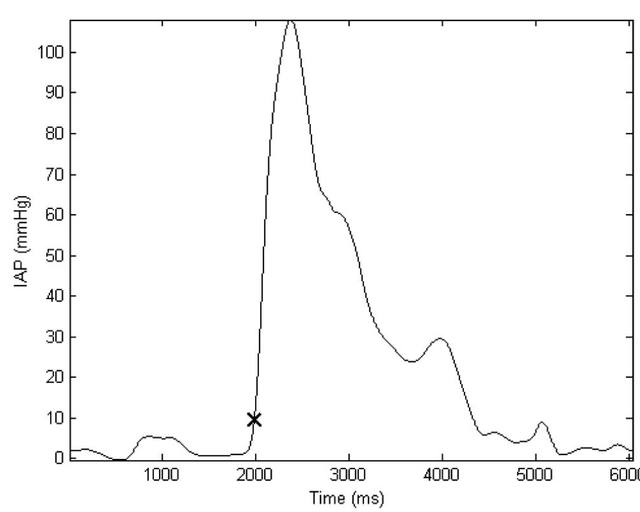

Figure 1. IAP time curve from a patient fall situation (male participant). The cross-mark shows the defined onset.

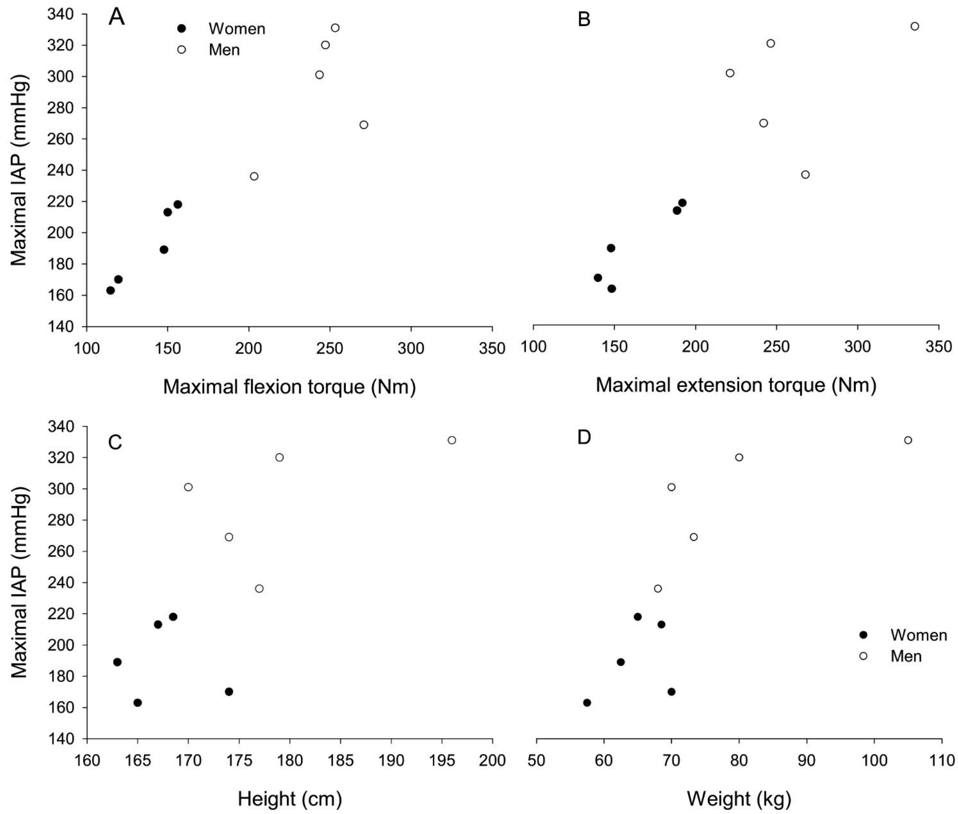

Figure 2. Maximal Valsalva IAP for men and women plotted against flexion torque measured during MVC (**A**), extension torque measured during MVC (**B**), body height (**C**), and body weight (**D**).

sion force at the L4–L5 joint. A dynamic three-dimensional biomechanical model was used for calculating the net torque at the L4–L5 joint.[24] Results from this calculation have been reported earlier.[12]

Calculations. The rate of IAP development (RID) was derived as the mean slope of the IAP-time curve over time intervals of 0 to 30, 0 to 50, 0 to 100, and 0 to 200 milliseconds, relative to a defined onset of the IAP development. In addition, the maximal RID (maxRID) was found as the peak values of the entire differentiated IAP-time curve. The calculation methods have previously been used to determine the rate of force development.[25] Onset of the IAP development was defined as the time point where the IAP exceeded 10% of the maximal IAP obtained through the Valsalva maneuver. Breathing and slow trunk movements made IAP fluctuate up and down, and to avoid these small fluctuations, a limit of 10% was used. Every onset was visually checked. An example is shown in Figure 1. The focus has been on peak values for all calculated parameters.

Statistics. When relevant to examine the influence of both sex and trial, a three-factor nested ANOVA with subject as random factor and sex and trial as fixed factors was used. When irrelevant to compare between trials or in case of interaction between sex and trial, one-way ANOVA was used to examine for differences between the sexes. Level of significance was set to $P < 0.05$. When $0.05 < P < 0.075$, it is marked in the tables. All results are presented as the average of peak values ± 1 SD, except RID in the four time intervals (mean ± 1 SD).

Results

From the reference contractions, it appeared that the men developed a higher IAP during Valsalva maneuver (men, 291 ± 39 mm Hg; women, 191 ± 25 mm Hg) and a higher trunk extension torque (men, 263 ± 44 Nm; women, 163 ± 25 Nm) and flexion torque (men, 244 ± 25 Nm; women, 138 ± 19 Nm) during the isometric

Table 1. Mean RID (mean ± SD) in the Four Time Intervals and Overall Maximal RID During the Modified Valsalva Maneuver and During the Patient Fall

Time Interval	Sex	0–30 ms (mm Hg/msec)	0–50 ms (mm Hg/msec)	0–100 ms (mm Hg/msec)	0–200 ms (mm Hg/msec)	Overall max RID (mm Hg/msec)
Modified Valsalva	Male	0.9 ± 0.4†	1.0 ± 0.5†	1.1 ± 0.4*	1.0 ± 0.2*	1.3 ± 0.3*
	Female	0.4 ± 0.2	0.5 ± 0.2	0.5 ± 0.2	0.6 ± 0.2	0.8 ± 0.2
Patient fall	Male	0.5 ± 0.2*	0.5 ± 0.3*	0.6 ± 0.3*	0.5 ± 0.2*	0.7 ± 0.2*
	Female	0.2 ± 0.1	0.2 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.5 ± 0.1

Note: Valsalva RID was higher than the patient fall RID.
*Significant difference between men and women.
†Tendency toward difference between the sexes ($0.05 < P < 0.075$).

Table 2. Peak Torques and IAP (mean ± SD) for Men and Women

	Sex	Total Torque (Nm)	Extension Torque (Nm)	Lateral Torque (Nm)	Rotation Torque (Nm)	IAP (mm Hg)	IAP (% max)
Symmetric lift	Male	182 ± 39.8*	182 ± 39.7*	11 ± 4.5	6 ± 4.0	67 ± 22	23 ± 8
	Female	133 ± 11.5	133 ± 11.4	8 ± 3.6	6 ± 3.3	58 ± 9.5	31 ± 5
No patient falls	Male	100 ± 22.6	98 ± 22.4	20 ± 7.5	9 ± 7.3	24 ± 14	9 ± 7
	Female	84 ± 33.8	83 ± 34.3	15 ± 7.7	5 ± 2.0	18 ± 11	9 ± 5
Patient fall	Male	271 ± 52.1*	257 ± 66.0*	75 ± 43.4	34 ± 14.2*	153 ± 27*	54 ± 12*
	Female	205 ± 49.3	192 ± 56.9	64 ± 34.7	22 ± 11.0	120 ± 14	65 ± 12

Total torque = the sum of the three torque vectors.
*Significant difference between men and women.

reference contractions. In line with these differences, the men were also taller and heavier (Figure 2).

The maxRID measured during the different Valsalva maneuvers was also higher in the men. But neither the men nor the women reached their maximal level during the patient fall (Table 1).

During the patient falls, the men developed a higher IAP than the women, but the peak extension torque and the peak total torque were also significantly higher among the men (Table 2). The associations between developed peak IAP and peak extension torque were not significantly different between men and women during the patient fall. The IAP is plotted against produced extension torque in Figure 3. When IAP was normalized to maximal Valsalva maneuver, it appeared that the women used a significantly higher percentage of their maximal IAP (Table 2).

The peak EMG levels for the different experimental situations are presented in Table 3. Few differences between the sexes appeared in the EMG activity obtained through the patient falls. In general, men exposed to the patient falls used equal or relatively lower level of muscle activity than women, except in the OI muscle.

The patient fall compared with the control trial caused a significant increase in the peak EMG activity for all but the RA muscle, which showed low activity through all trials. Highest activity was measured from the OI muscle along with the broad recording site, and the activity matched the developed IAP in general. In the bottom of Table 3, the EMG from the Valsalva maneuvers is presented. Again, lowest activity was observed in the RA, but the activity was 4 to 10 times higher during the Valsalva maneuvers compared with the functional situations. The women did not activate their abdominal muscles during the Valsalva maneuvers to the same level as the men. In Figure 4, the EMG and the IAP activity during a patient fall are plotted in real time. Note the very low level of RA activity.

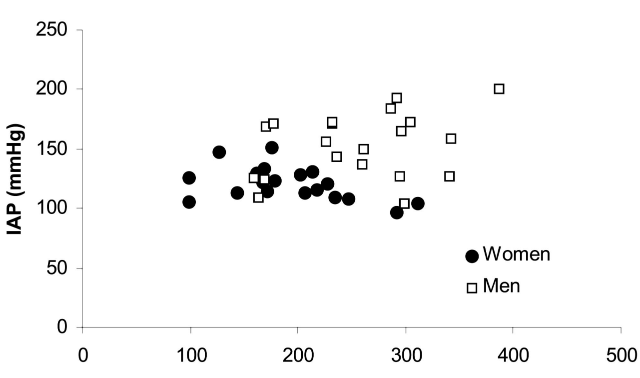

Figure 3. Peak IAP and peak extension torque during the patient fall for the male and female participants.

Discussion

Men compared with women developed a higher IAP and higher torques when the trunk was exposed to sudden heavy loads. In line with this, they also had a higher RID; however, as the IAP capacity among men was higher, relative levels appeared to be equal. None of the participants used their full RID or IAP capacity when exposed to the heavy sudden trunk loadings. But the women had to use a higher relative level of their IAP and extension torque capacity to comply with the heavy loads.

For this homogeneous group of participants, the variance in absolute IAP, torque, and RID levels could to a large extent be explained by the differences in anthropometrics rather than sex differences. For these well-trained participants, the association between the IAP and strength was linear (Figure 2). In relation to IAP and RID, it is important to remember that there are important anatomic differences in the pelvic floor between the sexes. Even though the female participants in the present study had not yet given birth, the muscles in the pelvic floor of the females may limit the possibility of developing IAP of the same size as the men. That the pelvic floor could be a limiting factor is indicated by the fact that during the Valsalva maneuver the women did not activate their abdominal muscles to the same relative levels as the men.

When the patient fell, the participants were able to be close to the patient and thereby get the load close to their center of support. In contrast, the distance to the load was fixed during the standard lifts and accordingly the women had to bend more forward because of their smaller reach and were relatively more loaded than the men. Even though the men experienced a higher extension torque, which can only be explained by their heavier weight of the arms and trunk. A rough estimate based on anthropometric tables[26] shows that the upper body of the men weighted 10 kg more than the women leading to an additional torque around 30 to 40 Nm.

Table 3. Peak EMG Levels (mean ± SD) Presented as % of the Maximal EMG Obtained During the Reference Contractions

	Sex	Broad Right	Broad Left	OI Right	OI Left	OE Right	OE Left	RA Right	RA Left
Symmetric lift	Male	9 ± 3	9 ± 1†	10 ± 6	10 ± 4	3 ± 2	3 ± 1	2 ± 1†	2 ± 1
	Female	11 ± 6	14 ± 7	10 ± 3	8 ± 2	4 ± 2	6 ± 2	3 ± 2	4 ± 3
No patient falls	Male	8 ± 5	12 ± 8	6 ± 2	9 ± 2	4 ± 3	7 ± 5	3 ± 2	3 ± 2
	Female	10 ± 6	11 ± 5	14 ± 13	12 ± 10	6 ± 4	7 ± 5	5 ± 3	4 ± 3
Patient fall	Male	33 ± 14‡	42 ± 27‡	36 ± 18*‡	39 ± 18*‡	9 ± 7‡	12 ± 5*‡	3 ± 2	4 ± 7†
	Female	42 ± 35‡	50 ± 39‡	22 ± 12‡	24 ± 15‡	16 ± 13‡	27 ± 22‡	7 ± 5	9 ± 10
Valsalva maneuvers	Male	51 ± 6§	65 ± 13*§	80 ± 18*§	81 ± 23*§	47 ± 20*§	50 ± 23*§	29 ± 14*§	24 ± 18§
	Female	51 ± 12	49 ± 11	44 ± 25§	41 ± 24§	29 ± 11§	28 ± 9	17 ± 7§	17 ± 11

OI = obliquus internus; OE = obliquus externus; RA = rectus abdominus.
*Significant difference between men and women.
†Tendency toward difference between the sexes (0.05<P< 0.075).
‡Significant higher than the situation without patient fall.
§Significant higher than during patient fall.

It has previously been found that at the same extension torque (L4–L5), women develop lower IAP compared with men.[27] This was not fully supported by the present data. Indeed, the women during the symmetric lift produced a lower extension torque than the men but an almost equal IAP. However, from Figure 3, it is seen that, especially for extension torques above 200 Nm, the men tended to develop a higher IAP at the same level of torque. It is also seen that in this narrow peak load interval there was no linear relationship between the IAP and the extension torque. When a broader range of load data are added, a linear relationship between the IAP and the extension torque exists.[12]

Thomas *et al*[28] found no sex effect in the EMG response to expected or unexpected symmetric and asymmetric trunk loadings. They used light standardized loadings. In this study, the women tended to have higher or the same level of EMG activity as the men except for the OI muscle during patient fall where the men showed higher activity. During the patient fall, the IAP was also significantly higher for the men, and this can explain the OI activity.

The levels of abdominal muscle EMG activity during the standardized lifts correspond to previously measured levels.[29] The patient fall caused increased muscle activity in all muscles except the RA. The very low level of RA activity is rational since activity would produce a flexion torque adding to the flexion torque from either the box or the patient and thereby increasing the load to be overcome by the extensor muscles.

The muscles producing force in the transverse plane (OI, OE) showed more EMG activity, and the broad site that intentioned to measure EMG activity of the TA showed along with the OI the highest activity. Because of their orientation of the muscle fibers, the OE and the OI do not add any significant flexion torque. We cannot be sure whether the broad measuring site has measured the activity of the TA, but most likely a substantial amount of crosstalk has been present.

During the heavy sudden trunk loadings, the IAP seems to be used as an internal airbag that very quickly can be blown up to increase the stability of the spine and trunk and perhaps unload the spine. As mentioned, both

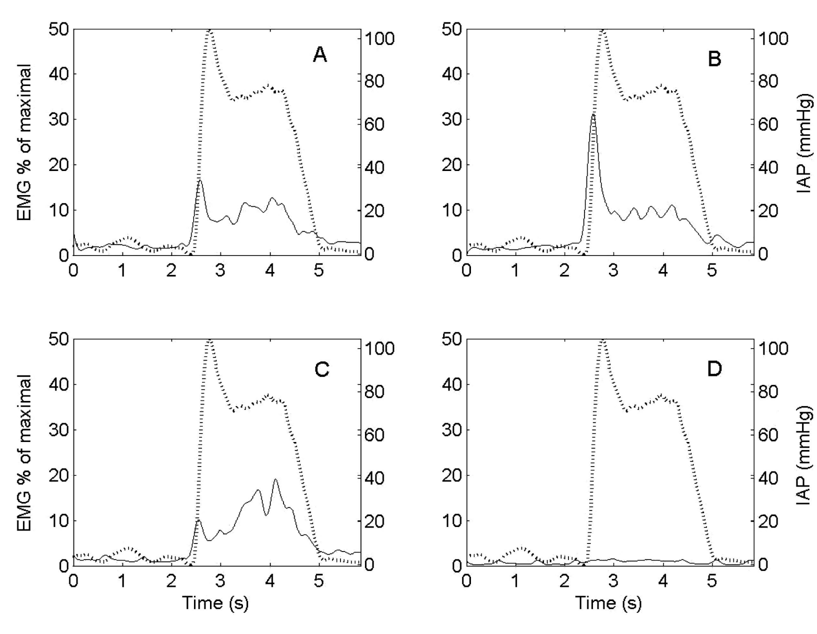

Figure 4. IAP (dotted line) and relative EMG activity of abdominal muscles (full-drawn line) in a trial where the participant is preventing the patient from falling: **A**, broad recording site; **B**, m. obliquus internus; **C**, m. obliquus externus; **D**, m. rectus abdominus.

model studies and actual measurement have shown that increased IAP can produce an extension torque in the low back.[14–16] The main argument against IAP's possibilities in producing an extensor torque has been that especially the RA activity would counteract such torque development.[7,15] A study on steady state isometric back extension concluded that it was impossible to generate IAP without trunk muscle cocontraction including RA,[17] which is supported by our EMG data obtained during Valsalva maneuvers. However, our data from the dynamic sudden heavy trunk loadings showed that the participants in these situations were able to develop a high IAP without any significant activity in the RA, thereby supporting the theory of the IAP adding to the extensor torque produced by the back muscles. Whether this is a learned skill through years of training or whether this is a common activation strategy is unknown.

It has previously been shown that IAP and the developed extension torque are closely timed during large sudden trunk loads,[12] and as these well-trained participants did not use their full capacity in the RID, it seems not to be a limiting factor. Maximal RID can be increased through training[13]; therefore, the RID may be insufficient in the general population.

There are limitations to this study. Our participants are well trained and very used to heavy sudden loadings of the trunk. Our data can therefore not directly be taken as an expression of the general population. The low number of participants increases the risk of making a statistical type II error. We found differences between the sexes in several parameters, but there may not be conformity between the sexes in the rest of the parameters. A limitation also relates to the determination of the onset of the EMG used for the RID calculation. The threshold of 10% of the maximal IAP is not beyond dispute. However, it is not likely that this definition should favor one sex in particular.

Seen retrospectively, it would have been advantageous to have the patient standing on an additional force platform. This would have made it possible to obtain information on the exact start of the patient fall, and even more important, it would have informed about how sudden the patient had fallen.

■ Conclusion

Men compared to women developed a higher IAP and higher torques when the trunk was suddenly heavily loaded. In line with this, the men have a higher RID; however, as mens' IAP potential is higher, relative levels appear to be equal. None of the participants used their full capacity when exposed to the heavy sudden trunk loadings. But the women had to use a higher level of their IAP and extension torque capacity to comply with the heavy loads.

The RA muscle does not contribute to the IAP development when the trunk is suddenly heavy loaded. Well-trained men and women are able to activate the abdominal muscles selectively and develop an IAP with minimal activity in the RA muscle. These results support the theory of IAP unloading the spine through a contributing extension torque.

■ Key Points

- Highly trained judo fighters performed simulated lifting accidents.
- High intra-abdominal pressure was quickly developed when the trunk was suddenly loaded.
- The rectus abdominus muscle did not contribute to the intra-abdominal pressure development.
- The well-trained judo fighters did not use their full potential of intra-abdominal pressure development.

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