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# RELATIVE EMG LEVELS IN TRAINING EXERCISES FOR ABDOMINAL AND HIP FLEXOR MUSCLES

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**ABSTRACT. The main purpose of our study was to compare systematically EMG levels in sub-maximal training exercises for the trunk and hip flexor muscles with those voluntarily attainable in corresponding situations. Six healthy subjects performed three types of standardized training exercises, whose static positions, movement velocity and range of motion were reproduced during maximal voluntary isokinetic strength tests. EMG was recorded with wire electrodes from the iliacus muscle and with surface electrodes from the rectus femoris, sartorius, rectus abdominis, obliquus externus and internus muscles. The relative EMG values demonstrated a task dependency which could differ between individual muscles. The maximal voluntary activation levels were relatively constant across conditions. Exceptions were present, particularly for the rectus femoris and iliacus muscles. These findings highlight the consequences of using different methods of normalizing EMG. The relative EMG values presented may serve as guidelines when selecting training exercises for specific trunk and hip flexor muscles in sports and rehabilitation.**

*Key words:* abdominal muscles, EMG, hip flexor muscles, iliopsoas, isokinetic, isometric, normalization, sit-ups, strength, training.

## INTRODUCTION

Movements and stability of the trunk are controlled by a complex array of different individual muscles. The activation of these muscles has been shown to be task specific (5, 6, 9, 20). In training this specificity has to be taken into account. One needs to know not only that a specific muscle is engaged in a particular exercise, but also to what extent. The only way to obtain such information is by recording the myoelectric activity via electromyography (EMG). Adequate methodology aids in obtaining information on the involvement level of a certain muscle. However, when attempting to make quantitative comparisons of the EMG levels, problems arise. Due to limitations in our ability to standardize recording conditions, absolute EMG levels are generally not comparable between muscles or individuals. To circumvent this problem one must perform some sort of normalization of the EMG values (7, 14, 23). Several methods of normalization are presented in the literature, each having its advantages and disadvantages.

Normalization of EMG has conventionally been carried out in relation to one set value, either submaximal or maximal. The use of a sub-maximal EMG value, which can be any recorded value, makes possible a comparison between different possible situations, such as when the subjects perform different exercises. If the absolute activity levels are low in the measured tasks, the differences between them will be more clearly distinguishable if they are normalized to a sub-maximal value. However, the pattern of EMG variation between tasks will be the same as when relating to the EMG during one single maximal effort. It has been argued that normalizing the EMG to an isometric maximal effort is less reliable than normalizing to a sub-maximal one, especially if an impairment is present making it hard for the subject to perform maximally (1, 30). Another approach, namely to relate the activation of a muscle to the highest activity level observed for that muscle in a large variety of presumably sub-maximal tasks, was used in an earlier study on the same type of training exercises as in the present investigation (6). Thus, the EMG levels present in a certain abdominal or hip flexor muscle can be varied widely by changing factors such as type of exercise and body position. By including numerous movements, also quite strenuous ones, one can approach a situation where the maximal voluntary activation is reached for a certain muscle. Furthermore, an indication can be obtained as to the best task to use for testing maximal efforts, if, for some reason, the highest maximum EMG value is to be determined.

The maximal EMG value for normalization can be obtained in different ways: as a maximal voluntary activation without other resistance than a co-activation of the antagonists, and/or as a passive resistance from these muscles with or without the moment created by the gravitational force. Interestingly, a maximal voluntary activation of the abdominal muscles performing a Valsalva manoeuvre resulted in clearly lower activity levels than when maximal torque is produced against an external resistance to trunk flexion (8, 9). The most common method is to normalize sub-maximal EMG values to the EMG in one standardized, often static maximal voluntary effort. If attempting to reach the highest level achievable voluntarily for a certain muscle, a variety of maximal efforts must be explored, since it is well known that the EMG can vary with, for example, position, even in maximal efforts (11, 13). It has also been shown that the maximal voluntary EMG may vary with the type of muscle action as well as the movement velocity (22, 28). These potential variables have not been considered in earlier studies using normalization of trunk muscle EMG data (17, 18, 27).

To account for these sources of variation, the logical thing to do would be to match the maximal EMG situation as closely as possible to the one where the sub-maximal EMG values are recorded. With respect to trunk training exercises, this has only been attempted in one study on sit-ups, using a single static position (12). Studies on trunk and hip muscle training exercises using such a matching paradigm in dynamic situations are, to our knowledge, still lacking.

The major objective of this study is, therefore, to compare the EMG activity of three abdominal and three hip flexor muscles during various static and dynamic training exercises with the maximal voluntary EMG produced in corresponding maximal strength measurement situations. In addition, a comparison is made between this normalizing technique and one where the training EMG is compared to one maximal value, namely the highest one obtained in the maximal efforts.

## MATERIAL AND METHODS

### *Subjects*

Six healthy, habitually active male subjects participated in the study. Their average age, body mass and height were 25 (22–29) years, 75 (65–84) kg and 1.81 (1.76–1.87) m. The study was approved by the Ethical Committee of the Karolinska Institute. All subjects gave informed consent for the study.

### *Training exercises*

Each subject was placed in a supine position on a horizontal bench (Fig. 1A). Two electrogoniometers were used to record movements. One was placed at the left trochanter major (a in Fig. 1A) for movements at the hip joint and the other under the bench with a string taped to the skin over the spinosus process of C7 (b in Fig. 1A) for movements of the upper body. Motions in trunk flexion and leg lift were indicated by each goniometer separately, whereas both goniometers responded to movements in the hip flexion exercises. In all exercises the arms were kept crossed over the chest. When raising the whole trunk, the head was held in a neutral position. A rest period of approximately 2 minutes was given between each separate task.

Three training exercises were tested (Fig. 1B): (1) trunk flexion (TF), with no movement at the hip and with the lumbar back in contact with the bench; (2) hip flexion (HF), i.e. lifting a straight upper body via the hip flexors; and (3) bilateral leg lift (LL), i.e. hip flexion with straight knee joints. TF and HF were performed with straight and supported legs.

The recorded static positions for TF were 10°, 20°, and 30° with a maximal angle of approximately 40°–45°, and for HF and LL the positions were 10°, 30° and 60°. The angles were measured between the horizontal plane and a line from C7 to the center of rotation (in TF approximately at T12–L1 level and in HF at the hip joint) when raising the upper body, and in LL from the centre of rotation (the hip joint) to the lateral malleolus. The dynamic training exercises were performed at a mean velocity of approximately 30°/second, following the rhythm of a

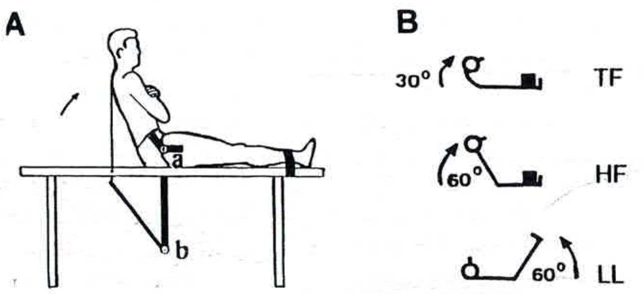


*Fig. 1.* A. Experimental set-up for the training exercises. The hip goniometer (a) indicates movement at the hip; the bench goniometer (b) records both trunk and hip movements. B. The different training exercises tested: trunk flexion (TF), hip flexion (HF) and leg lift (LL). TF and HF were performed with straight and supported legs, and LL as a bilateral lifting of straight legs. (For further description, see Methods.)

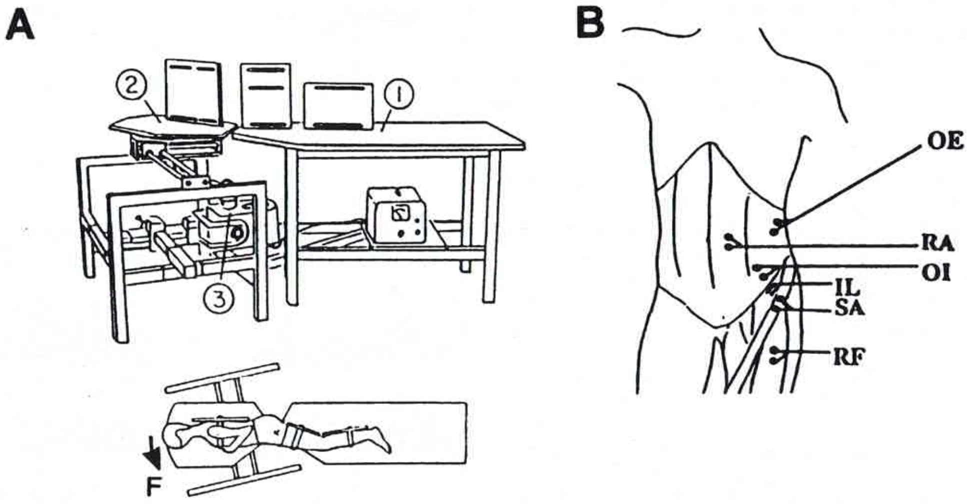


*Fig.* 2. A. Experimental set-up for measurements of maximal trunk and hip flexor muscle strength, with body position in hip flexion movements (HF pivot: hip joint) shown below. B. Positions of the surface electrodes on the three abdominal muscles (RA, OE and OI) and two of the hip flexor muscles (RF and SA). The site for insertion of the intra-muscular fine-wire electrodes into the third hip flexor muscle (IL) is also indicated. (For further description, see Methods.)

metronome set at 1 Hz. The movement ranges were 0°–30° in TF and 0°–60° in both HF and LL (0° = straight body) (Fig. 1B). Thus the duration of the upward phase was about 2 seconds in HF and LL as compared to about 1 second in TF. A manual goniometer was used to obtain proper static positions and to set the upper limit for movement in the dynamic exercises. Each static task was performed once, and for the dynamic tasks one representative cycle was selected out of four to five. No estimate of intra-individual variability was made.

*Maximal strength measurements*

Strength measurements were performed in positions and with pivot points, ranges of motion and mean velocities corresponding to those in the training exercises (TF, HF and LL). An isokinetic (constant velocity) technique (Cybex) adapted for trunk and/or hip muscle strength measurements was used (25). The recordings were made on the horizontal plane with the subject lying on the right side. The experimental set-up is shown schematically in Fig. 2A along with the positioning of the subject for measurements of hip flexion strength, i.e. with the hip joint as pivot point (HF). For HF and TF strength, the lower part of the body was strapped to a rigid table (**1** in Fig. 2A), and the upper part to a swivel table (**2** in Fig. 2A), which could be moved or fixed at a certain angle, in an arc of motion covering the major part of the movement range for the respective movement. In LL, the body position was reversed from that of HF, i.e. the legs were placed on the swivel table. In all cases the respective centres of rotation of the body were positioned right above the connection between the tables. Pivot points and angles were defined as for the training exercises (cf. above).

The recorded static positions were, for TF, 10°, 20°, and 30° with a maximal angle of approximately 40°–45°, and in HF and LL the positions were 10°, 30° and 60°. The movement ranges were 0°–30° in TF and 0°–60° in HF and LL, all movements performed isokinetically at 30°/second. The subjects were told to perform maximally over the whole range of motion. After practising each strength exercise at a level close to maximal, subjects performed the various static and dynamic tasks once during the recording session. A second trial was allowed if the subject felt the first one was sub-maximal or the quality of the signals was unsatisfactory. The maximal voluntary strength (torque) produced was transmitted via the lever arm of a Cybex-dynamometer (**3** in Fig. 2A), placed underneath the table. However, the Cybex was only used to control the velocity and record positions; the torque values were not analysed in this study.

*Electromyography*

Electromyographic (EMG) recordings were made on the left side of the body (Fig. 2B) with surface electrodes from the abdominal muscles rectus abdominis (RA), obliquus externus (OE), and obliquus internus (OI), and from the hip flexor muscles sartorius (SA) and rectus femoris (RF). The surface electrodes were Beckman miniature silver/silver chloride electrodes, with a pick-up area diameter of 4 mm, and a fixed inter-electrode distance of 8 mm. The EMG of the hip flexor muscle iliacus (IL) was recorded with indwelling bipolar finewire electrodes. The wires were of stainless steel, 0.22 mm in diameter, Teflon insulated except for 3 mm at the tip, with a 5 mm inter-electrode distance when hooked to a needle (0.7 × 70 mm). The needle was inserted with the wires, after hypodermic local anaesthesia, about 3 cm lateral to the femoral artery, 1 cm medial to the sartorius muscle and 1 cm inferior to the inguinal ligament to a depth of 3–4 cm from the skin surface (Fig. 2B). The needle was then withdrawn, leaving the wires in the muscle belly. The position of the wires in the iliacus muscle was confirmed by means of ultrasound in one subject (3, 4).

All EMG signals were differentially pre-amplified (100 times) close to the site of the electrodes using customized lightweight amplifiers attached to the skin. Signals were then band-pass filtered at 10–1000 Hz, further amplified (10–50 times) and collected together with the signals from the goniometers on magnetic tape for subsequent analog to digital conversion and computer analysis. The sampling frequency was 0.5 kHz.

In the dynamic training exercises mean EMG amplitude was quantified from the rectified EMG signals during the upward (concentric) phase of each movement cycle, beginning 200 ms before the start of motion (see Fig. 3), and in the static exercises during the first two seconds after a stable position had been attained. During the maximal dynamic strength measurements the mean EMG amplitude was calculated in a similar fashion, i.e. over a corresponding range of motion (0°–30° in TF, 0°–60° in HF and LL), beginning 200 ms before the start of the movement. In the maximal static strength tests the EMG values were taken during the first two seconds at each stable static position.

The mean EMG amplitudes for each individual muscle in the different dynamic and static training exercises were normalized to, and expressed as a percentage of, the EMG during corresponding maximal voluntary strength measurements. Further, the activity levels in all training exercises were normalized to only one EMG value, the highest absolute activity level observed for each particular muscle in any of all recorded maximal efforts. For the two normalization techniques separately, the mean of the percentage values (± SE) in each exercise was calculated for the six subjects for each individual muscle. Further, the mean activity levels for the abdominal (RA, OE, OI) and hip flexor synergies (IL, RF, SA) during a specific task were calculated by obtaining the mean of the individual percentage values for the six subjects of all three muscles included in each synergy.

*Statistics*

Differences in the normalized EMG activity levels between all training exercises, for individual muscles and the two muscle synergies, were tested for significance, for the two normalizing techniques separately, with a one-way ANOVA, using a repeated measures design with one repeating factor. The Duncan post-hoc test was used to identify significant differences between specific tasks ($p < 0.05$).

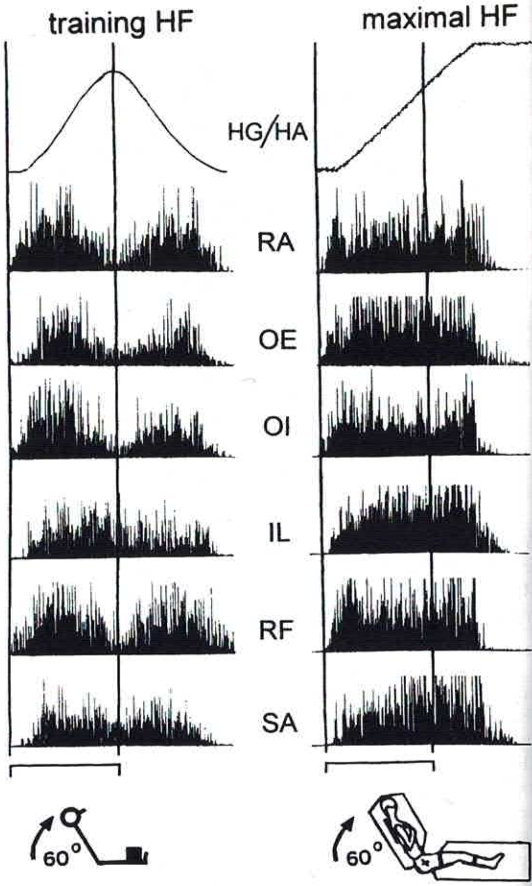


*Fig. 3.* Typical recordings in dynamic hip flexion (HF) during the training exercise and the corresponding maximal strength test. The graphs represent angular displacement of the hip goniometer (HG) and the goniometer of the dynamometer (HA), rectified and filtered EMG from RA, OE, OI, IL, RF and SA. The amplifications and scales of the EMG recordings for each muscle are equal in the two tasks. The mean EMG amplitude during the upward phase of the dynamic training sit-up movement was measured in percent of the mean EMG obtained at a corresponding range of motion in the maximal strength measurement, starting 200 ms prior to the onset of motion. The interval analysed (0°–60°) is marked below, including the initial 200 ms. (For further description, see Methods.)

## RESULTS

Typical EMG recordings are shown in Fig. 3 for the dynamic training exercise HF and the corresponding maximal strength test. In general, the appearance of the EMG and angular displacement curves for each task was similar for all subjects. In the HF training exercise the abdominal muscles showed a decrease in activity with an increased degree of hip flexion. No such decrease was observed during the maximal isokinetic strength test. In the TF training exercises a pattern of increased abdominal activity with a higher trunk flexion angle was present, whereas in LL the EMG levels were independent of hip angle in the training exercises.

### *EMG in training exercises in relation to the EMG levels during the corresponding maximal strength measurements*

Mean activity levels for the six subjects in the different static and dynamic training exercises (expressed in percent of the corresponding maximal strength tests) are shown for each muscle in Fig. 4 (for exact data, tables are available from the authors.)

*Static tasks:*. In TF, EMG values increasing with trunk flexion angle were observed for all abdominal muscles. The relative levels increased from 21% ± 3% to 56% ± 7% for the abdominal synergy. Among the individual abdominal muscles, the highest involvement at maximal trunk flexion angle was observed for RA (70% ± 19%) and the lowest for OE (44% ± 11%). In HF, the abdominal activity decreased with a more flexed hip position. It should be noted that among the three abdominal muscles, RA showed the highest relative involvement at the initial HF angle, 10° (81% ± 11%), whereas at the final angle of 60°, the values for RA were lowest (31% ± 13%). In LL, no significant difference was recorded for any of the individual abdominal muscles in the different positions (38% ± 7% to 53% ± 8%). The levels for the abdominal synergy were highest at 10° of HF (76% ± 6%), which is significantly different from the level of 60° of HF (41% ± 7%) and all LL positions (41% ± 4% to 47% ± 5%).

The relative level of EMG activity for the hip flexor muscles was not calculated in TF, neither for the static nor the dynamic tasks, since the absolute values were very low in both cases and the percentage values therefore can be misleading. In HF, the relative EMG values did not change significantly with hip angle for any of the individual hip flexor muscles, being highest for RF (68% ± 20% to 76% ± 10%), somewhat lower for SA (47% ± 16% to 63% ± 19%), and lowest for IL (36% ± 20% to 45% ± 16%). In LL, on the other hand, all individual hip flexor muscles showed a tendency to increase percentage values with higher hip flexion angle. However, the differences were not significant.

*Dynamic tasks:*. Among the abdominal muscles, OE showed significantly lower values in TF (30% ± 12%) as compared to HF and LL (70% ± 10% and 62% ± 11%, respectively). RA, on the other hand, showed a tendency (n.s.) towards a decrease of the relative EMG values, from TF (90% ± 16%) to HF (71% ± 9%) and further to LL (59% ± 11%), whereas OI had similar values in all three exercises (42% ± 2% to 61% ± 7%). As a result, the whole abdominal synergy demonstrated similar values in all dynamic tasks (varying between 54% ± 5% and 67% ± 5%). Note ,that the abdominal muscles have a dynamic (concentric) muscle action in TF, whereas it is static in HF and LL.

Two of the hip flexor muscles showed a tendency (n.s.) towards higher EMG levels in the LL as compared to the HF exercise (IL 60% ± 13% vs 48% ± 10%, and SA 69% ± 7% vs 55% ± 10%). RF, on the other hand, demonstrated the opposite tendency (53% ± 12% vs 72% ± 8%). As a result, the flexor synergy presented equal values for the two tasks (61% ± 6% vs 59% ± 6%).

### *EMG in training exercises in relation to the highest EMG observed during strength measurements*

Mean activity levels for the six subjects in all different static and dynamic training exercises, expressed in percent of the highest absolute individual EMG value in any of all the maximal strength tests, are shown for each muscle in Fig. 4 (for exact data, tables are available from the authors.)

Since the highest observed EMG value was used for normalization, the relative EMG values were consistently lower than those obtained when the normalization was made as compared to the EMG obtained in the corresponding maximal strength test. Generally, the overall mean EMG levels for the six subjects were of the same order of magnitude during the different maximal strength tests. This means that the same trends were present for both types of normalized values with respect to variation of body position and type of exercise. This was generally true for both abdominal and hip flexor muscles. However, there were a few exceptions. The SE values were lower when normalizing to the highest maximal value than when normalizing to each corresponding maximal effort.

In static TF the involvement at the most flexed angle was 50% ± 13% for RA, 30% ± 5% for OE and 32% ± 7% for OI. These values were markedly lower as compared to the initial HF position especially for OE and OI (57% ± 4% and 47% ± 8%, respectively). In all LL positions the levels were equal irrespective of hip angle, varying between 19% ± 3% and 33% ± 9% for all abdominal muscles.

In the static tasks, RF demonstrated the most conspicuous difference. When normalizing to the EMG during the highest maximal effort, a significant decrease was present for RF between the initial and final angles in the HF training exercises. The result was that for HF at 60°, the value relative to the highest maximal EMG value was much lower than in the corresponding maximal strength test (22% ± 5% vs 68% ± 20%). Thus the EMG during the corresponding maximal strength test at this angle was clearly lower than the highest observed for RF.

In LL, there was also a tendency for maximal RF activity to decrease with hip flexion angle and thus a

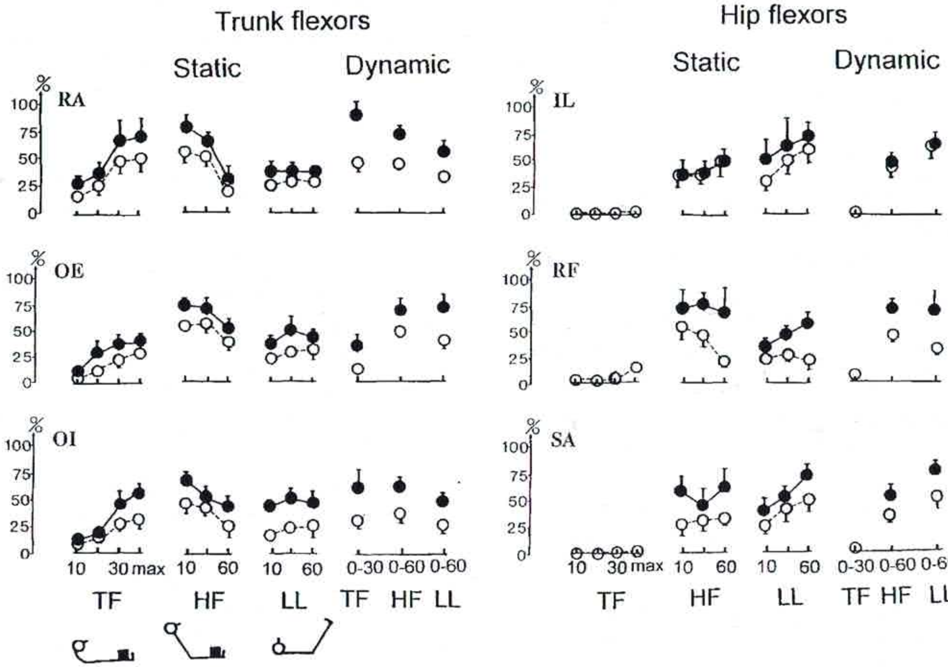


*Fig. 4.* Mean EMG amplitude values (± SE) for the six subjects for each muscle in the training exercises expressed either in percent of the values obtained during the corresponding maximal strength measurements (filled circles), or in percent of the highest observed individual EMG during any of the maximal strength tests for that particular muscle (open circles). Static values are connected with straight lines to facilitate interpretation. (Abbreviations are explained in Methods.)

trend (n.s.) was observed towards larger differences between the two methods of normalization in more flexed positions. In contrast, IL showed an increase in maximal EMG level when the hip joints were flexed in LL. This resulted in a larger increase in relative EMG with hip angle in the LL training exercise when normalizing to the highest maximal EMG (significant: from 27% ± 7% to 59% ± 10%) as compared to the corresponding maximal EMG (n.s., from 49% ± 19% to 72% ± 13%).

In the dynamic tasks, no major differences in activity pattern were present between the two normalization techniques, i.e. the maximal EMG values for the different muscles did not differ significantly between TF (only abdominals compared), HF and LL. It is noteworthy, however, that RA showed markedly lower relative values in dynamic TF when normalizing to the highest observed activity level than in relation to the corresponding maximal strength test (43% ± 7% vs 90% ± 16%). This situation was caused by a tendency towards lower maximal EMG values for RA in this exercise, although the differences between all maximal efforts were not statistically significant. OE showed a strikingly low value (14% ± 3%) in dynamic TF.

## DISCUSSION

The new approach in this study was to compare systematically the EMG levels obtained in sub-maximal training exercises for the trunk and hip flexor muscles with those voluntarily attainable in situations matched for body position and movement velocity. The results showed a considerable task-dependent variation in relative EMG values. Interestingly, this variation could differ between individual muscles within both the trunk and hip flexor synergy. However, since the maximal voluntary activation levels were relatively constant across conditions, the general pattern of EMG variation with task became similar to the circumstances when using a single maximal EMG value for normalization. Exceptions were present, particularly for the rectus femoris and iliacus muscles. These findings indicate the need to consider carefully the methods of normalization when evaluating relative muscle activation for various purposes.

*Normalization techniques*

Normalization of EMG recordings is generally necessary in order to make comparisons of activation levels between muscles and muscle groups within as well as between individuals (7, 14, 23). Several methods for normalization of EMG have appeared in the literature, using EMG values from both sub-maximal and maximal efforts as reference values.

When the intention is merely to compare the pattern of variation in the EMG for a certain muscle between situations, any recorded EMG for that muscle can be used as a reference value. Naturally the percentage values will vary widely depending on which reference value is chosen. A consequence of having a sub-maximal reference value is that relative values exceeding 100% are likely to occur.

Often there is a desire to relate recorded EMG levels to some sort of maximal voluntary EMG level. This is common when evaluating the possible training effect of a certain exercise in sports and rehabilitation as well as when assessing the load on the body or on a certain joint (in a workplace situation, for example.) As shown here and in other studies (16, 21, 24, 27, 29), the maximal level of EMG attainable may vary with the situation in which it is being produced. Individuals also vary as to the situations in which the highest EMG will occur. Thus the relative EMG levels obtained are critically dependent upon which maximal value is selected as a reference.

With regard to one single maximal value, such as the highest observed EMG among several maximal tests, it is important to realize that due to task specificity, the likelihood of obtaining a value closer to the highest possible EMG for a specific muscle increases with the number of different maximal voluntary efforts applied. On the other hand, there is no guarantee that the situation with the highest possible EMG will be included in the tests applied. For example, a comparison of the present data with those of our earlier study (6), which involved a large number of different motor tasks in which a maximal effort *a priori* was not requested, shows that some muscles had higher absolute EMG values than in the maximal strength tests of the present study (see also 16 and 17). Of course, the higher the maximal value used as the single reference value, the lower the percentage values will be for the EMG in the exercises compared to it, and vice versa (cf. below).

An inability to produce a truly maximal voluntary activation can be attributed to several factors of both central and peripheral origin in the neuromuscular system. Lack of familiarity with the test situation can cause a conscious or subconscious decrease in central drive to the motoneuron pool. This can be counteracted by having the subjects perform several pre-test trials, as in the present study, and/or several test trials in each situation. Peripheral input from pain receptors stimulated by the extreme effort or provoked by a physical impairment may result in lower excitation levels and lower maximal voluntary EMG. Similar effects could be caused by other inhibitory mechanisms, such as reciprocal inhibition if antagonist muscles are simultaneously activated.

Even if the voluntary effort is maximal, the absolute EMG level may vary between situations, as was the case in this study, particularly for the rectus femoris and iliacus muscles. One contributing factor could be the change in muscle length that accompanies changing trunk and hip angles. Muscle length changes are known to affect the maximal EMG output. However, there is no general agreement on how the central nervous system activates a muscle that operates at non-optimal lengths. Evidence for all three possible outcomes of a changed muscle length on the EMG has appeared in the literature (for references, see 11). Interestingly, the three hip flexor muscles, IL, RF and SA, showed different patterns of maximal EMG in relation to an increased flexion at the hip joint: IL an increase, RF a decrease and SA no change. This indicates that the length dependency of the maximal EMG may vary between muscles, even within the same synergy. The importance of relating EMG obtained in static tasks to maximal values in the same body position/joint angle has been noted before (18, 19, 27, 31) and is further emphasized by the present findings.

Only one previous sit-up study has attempted to normalize the EMG to a maximal effort in an equivalent position. This was done for one exercise, maximal trunk flexion angle, by Ekholm et al. (12). They reported the activity levels for RA and OE to be 50% of the corresponding maximum, which is comparable to our values of 44% (OE) and 70% (RA). One difference between the two studies is that resistance was applied manually on the shoulders in their case and by a belt around the chest in ours. Another difference is that the maximal strength tests in this study were performed in a side-lying position. This might affect the overall level of activation due to its different sensory input as compared to lying on the back, but will hardly affect the patterns of individual muscles.

In this study the comparison of training and maximal tasks was brought one step further by including not only several static, but also some dynamic measurements. By matching range of motion and average angular velocity, equivalent situations could be achieved. This equivalence is harder to achieve the more ballistically the training exercise is executed. It should be noted that only the concentric part, and not the equally often performed eccentric one, i.e. a controlled lowering of the lifted body segment, was analysed here (cf. 6). The corresponding EMG patterns during eccentric muscle actions may differ from those obtained here (cf. 10, 22, 28).

The technique of normalizing sub-maximal EMG to the corresponding maximum is not suitable for exercises where the involvement of a certain muscle is low despite a maximal voluntary effort. This was evident for RA in twisting actions in the study by McGill (16) and for the hip flexor muscles during maximal trunk flexion in this study.

### *Evaluation of training exercises*

In the training literature there is a general consensus that the relative load put on the muscle is important for the training effect that may result after a period of repetition. Empirically it is also widely accepted that a high relative load is needed to get a strength training effect. Values discussed are often about 60%–70% of "maximum". This maximum usually refers either to the maximum strength at a particular joint (MVC, maximal voluntary contraction) or to a specific strength performance such as a lift (1 RM, one repetition maximum). Given that there is a relatively strong positive relationship, either linear or curvilinear between activation level and force output in a given situation (e.g. 7, 15), the activation level, as recorded with EMG, may be taken as an indicator of the load put on the neuromuscular system relative to the maximum in that situation. In this study, however, no attempt was made to extrapolate the EMG to a force or load other than the "load on the activation". Within the limitations outlined above, we believe that the values presented here relative to the corresponding voluntary maximum may serve as guidelines when selecting training exercises for specific trunk and hip flexor muscles in sports and rehabilitation contexts. Values are available in Fig. 4 for application and comparison; only a few of the general trends will be commented upon below.

For the abdominal muscles, the highest relative activation levels were present in the static HF exercises, particularly in the initial positions (53%–81% of corresponding maximum). It is noteworthy also that during the dynamic HF and LL exercises the abdominal muscles acted statically with a corresponding range of activation levels (42%–71%). Applying the criterion of 60%–70% activation, these values were reached by RA in dynamic TF and static TF at flexed angles, and in dynamic HF and static HF at initial angles for all the abdominal muscles tested. If the "load on the activation" was measured in relation to the highest maximal EMG observed, the values did not exceed 60% for the abdominal nor the hip flexor muscles in any of the training exercises.

For the hip flexor muscles, some interesting differences were present among the three muscles when comparing the HF and LL exercises. RF had higher activation levels in static HF than LL, whereas the opposite was true for IL. SA showed, like IL, increased activity with angle in LL.

The activation of the hip flexors was negligible in trunk flexion exercises. Therefore this exercise can be used if selective engagement of the abdominal muscles is desired. In all the other exercises tested, there was co-activation of all the recorded abdominal and hip flexor muscles, albeit at different levels relative to their corresponding voluntary maximum. A selective activation of the hip flexor muscles can be achieved by performing unilateral leg lifts (4, 6). Inclusion of training exercises engaging hip flexor muscles along with other, more often included exercises, would be relevant for sports as indicated by findings of high relative strength in elite athletes in sports such as gymnastics (2). Their inclusion in rehabilitation programs would also be appropriate as indicated by reports on low relative values for maximal strength in hip flexion for patients with non-specific low back pain (26), naturally with the proviso that the training tasks can be carried out without discomfort and that they are accompanied by proper stretching exercises.

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