Methods of functional testing during rehabilitation exercises

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Testing muscle functions

The assessment of muscle strength, power, range of motion, stiffness and flexibility is important in exercise science. Similarly, evaluation of neuromuscular behaviour is of extreme relevance and interest in the field of rehabilitation of the sport injures. Consequently several test methods and techniques have been used to provide information regarding the relevance of strength and power to various physical pursuits - and to monitor progress of rehabilitation from injures (63).

The physical characteristics are dependent from several factors, including structure and function of the nervous system, structure and biochemical profile of skeletal muscle, mechanics of the joints and levers, and external mechanics. Each of these components has its specific influence on a given performance trait, but more important, they are all interdependent. Their proper integrative function for neuromuscular performance is of great relevance. Therefore, the development and refinement of valid reliable tests of muscular function are one of the pillars upon which rehabilitation of sport injures is based.

It should be remind that during injured conditions and after surgery, satisfactory results can be obtained only through the combined efforts of the surgeon, patient and therapist. A rehabilitative plan is based upon consideration of the effects of disuse and immobility on musculo-skeletal tissues, and knowledge of the healing requirements following injury and specific surgical procedure (56). A balance must be made between simultaneous demands for protection against undue stress to facilitate healing and the need for stress to retard atrophy of musculo-skeletal tissue.

The physic approach to sport rehabilitation is based upon progression in a logical fashion through the chronology of immobility, range of motion, progressive weight bearing and strengthening exercises. The latter category can be subdivided into its own progression from isometric, isotonic (iso-inertial load), functional exercises through isokinetic exercises. The ultimate goal, and final phase, is a safe return to full activity. On the other hand, it has been suggested that in clinical practice the post-immobilisation rehabilitation should be early and effective (42). To help the long process, which goes from injured conditions to normal physiological behaviour, the rehabilitation programs can be effectively helped by the assessment of muscle behaviour. This should be performed periodically during the training period for monitoring the effect of training on neuromuscular functions and specific performances.

Furthermore, the evaluation utilised to follow up the training program could be used, in case of injures or surgery as clinical basic data for assist and programming rehabilitation exercises. In providing this information it is important that the test modality used has relevance to the performance of interest.

In this contest both dynamic and isometric muscular activation have been employed for tests and evaluation assessments. However, the reliability of a testing protocol should be sufficient enough so that measures for training or injury induced changes in muscle strength cannot be attributed to instrument or testing error.

Isometric test

Isometric evaluation of muscle behaviour, which measures a muscle's maximum capacity to produce static force, has proceeded with different and often opposite results (7, 29, 32, 45, 49, 66, 74). One of the major limitations of such tests is that they are not specific to the performance of most human movements that require dynamic activation of musculature through a movement range. In addition, in previous research there have been large variations in the angle used in the isometric assessment. For example isometric leg extension tests have been performed with large range of knee angle (90–140^{o}) (35, 62, 65). However, recent research indicated that, whenever isometric test is used as predictors of performance, the joint angle used should not be arbitrary. In fact the relationship between the isometric tests themselves, and between the isometric tests and performance, varies substantially as function of the angle (52). These authors have recommended that isometric tests should be performed at the angle at which peak force was achieved in the performance of interest. In contrast, it has been suggested (63) that isometric testing be performed at joint angle which corresponded to peak of the strength curve for the particular muscle group, to reduce the variability associated with small error in the determination of joint angle.

Although isometric measurements can be performed using not only one joint angle (Fig.1A), but multiple joint angles (Fig.1B, C), isometric force has been poorly related to dynamic performance (e.g.7, 49, 50). In a longitudinal study, performed with Finnish national male volleyball team, it was noted that the decrease of heavy resistance training and the beginning of utilisation of jumping drills induced an enhancement of jumping performance, but was accompanied by a reduction of isometric force (7). No relationship between jumping performance and isometric force has also been reported in several publications (74, 81). The rise of tension development (RTD) most probably represents the point in force time curve where the amount of active motor units and/or their firing frequency is maximal (74). RTD calculated during dynamic concentric movement was superior to isometric RFD in its relationship to dynamic performance (60). It was suggested that there might be differences in

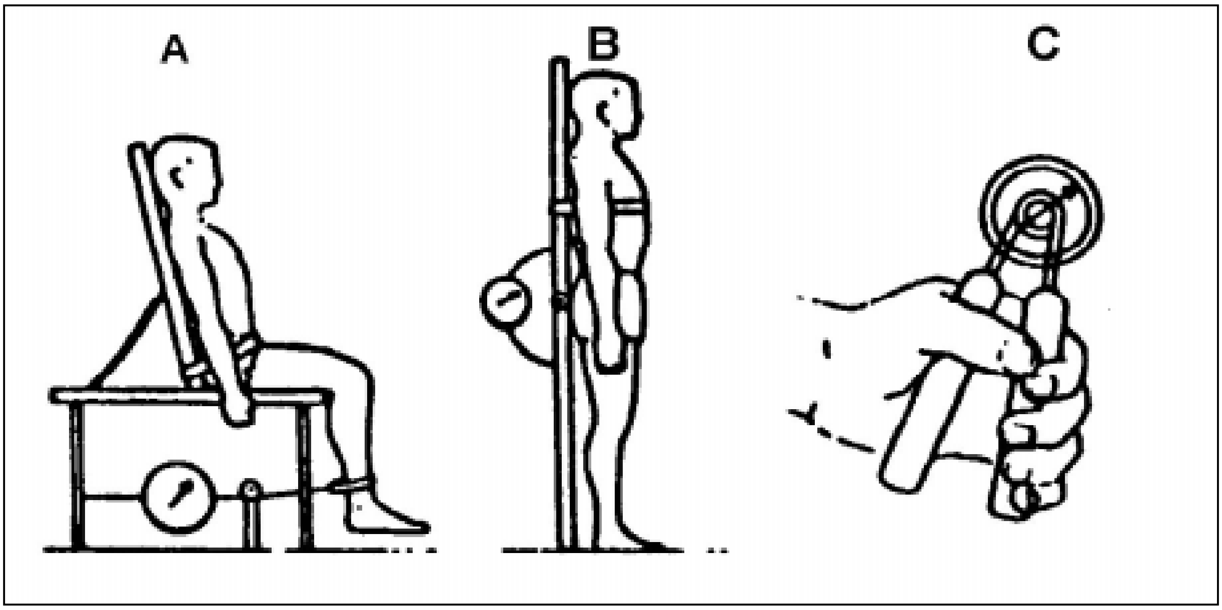

Fig.1 A, B, C. Example of different methods utilised for assessment of isometric maximal strength.

the neural activation of muscles between isometric and dynamic activation. Furthermore, the isometric rate of force development test was an ineffective to monitor training induced changes in performance of the triceps brachii and pectorals major of twenty-four male subjects (50). Such result supports the suggestions that specific recruitment patterns are developed for dynamic contractions and that this patterns differ to motor unit recruitment during isometric activity (3). Consequently, alterations to training programs for athletes should be based on changes in actual performance, as opposed to muscular function tests. These findings appear to be due to the large neuronal and mechanical differences between dynamic and isometric muscular actions. In light of the above observations is recommended that isometric assessment of dynamic performance should be avoided and dynamic forms of muscle assessment should be employed. However since isometric evaluation are popular tests to enhance their reliability and validity it is recommended to (76):

- Study participants perform a separate familiarisation session prior to the collection of data.
- Several repeat trials are performed, particularly if accurate RFD data is required.
- Clear and appropriate instructions are given.
- Negligible pretension to be allowed prior the test.
- The test is performed in a position specific to the performance of interest.
- The angle which involve the highest force out-put in the performance of interest be used in the isometric test. Alternatively a number of joint angles should be assessed.

Isokinetic

Since the inception of the isokinetic concept (37), this form of exercise has been thought to be a valuable tool for assessment and evaluation of muscular function and pathology. Isokinetic devices allow individuals to exert as much force and angular movement they can generate. Some of the advantage of isokinetic exercise and assessment has been advocated to be the following:

- Gives the possibility to isolate muscle groups.
- Single joint assessment allows a better isolation of specific diagnostic problems than multi-joint test, and therefore it is desirable to utilise isolated test for identification of specific problem.
- Provides accommodating resistance to maximal exercise throughout the range of motion.
- Collects quantifiable data for analytic evaluation.
- Allows for the examination of muscle output at certain sub-maximal velocities (40% of Vmax) throughout the movement range and therefore are often considered more specific to human physical performance than isometric assessment.
- Allows building the torque/ velocity (T/V) relationship (Fig. 2).
- Allows high reproducibility (r=0.82–0.96), of the tests protocol used (59, 77) if gravity correction and patient set-up are properly considered (78)

On the other hand several limitations are connected with this peculiar muscular activity:

- Isokinetic motion shows non-specificity with typical human movement characterised by the acceleration and deceleration of a constant mass (e.g.17).
- Isokinetic tests have not always provided data that accurately differentiate performance between athletes of varying skill levels (e.g. 29, 38).

- The maximal velocity allowed by isokinetic apparatus reaches only 40% of the maximal velocity (Fig. 2) that can developed by leg extensor muscles during ballistic motion (15) - and only 10% of the maximal velocity obtained by shoulder during throwing motion (55).
- Exercise occurs primarily from non-weight bearing open kinetic chain (OKC) positions, even if now day many isokinetic dynamometers can be used as a closed–kinetic chain (e.g. 48).
- Recent results (30) support the belief that isokinetic strength does not correlate strongly with functional tasks.
- Inability of the isokinetic dynamometer to detect increases in quadriceps performance has been also presented (2, 80). Those findings should be taken in serious consideration since the isokinetic values are frequently used as criteria for return to functional activities.

Although isokinetic tests have been extensively employed, recent observations are strongly questioning the real effectiveness of such evaluation. In this connection new approach for assessment of muscle functions in programming sport activity and rehabilitation exercises have been applied using iso-inertial evaluation.

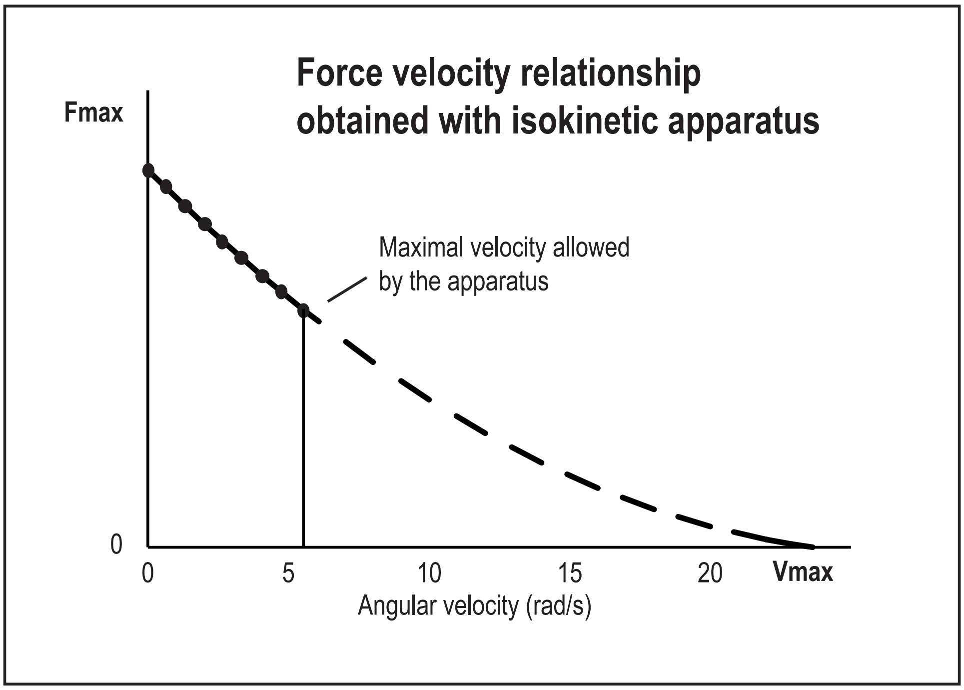

Fig. 2. Schematic representation of the torque/velocity relationship using isokinetic devices. The maximal speed allowed by these apparatus represents not more than the 40 % of the maximal velocity developed in ballistic motion.

Iso - inertial test

From physiological and functional point of view, the best tests of muscular behaviour are the ones using iso-inertial loads. Among these, the dynamometers, which utilise rotator inertial masses, have been built only for research purposes and therefore were not commercially available (40, 73). The assessment of the muscle function in dynamic conditions has only recently been performed against a constant mass - rather than a constant velocity, using commercial dynamometers. For these purposes several apparatus have been utilised, from force platform (e.g. 11) to a special sledge apparatus built ad hoc to study stretch-shortening cycle (41). An electronic processing unit that can be used with any muscular machine using gravitational forces (e.g. leg press, dips, pull down, barbells, etc.) as external resistance, has recently been developed (8, 9, 19, 20). This apparatus (MuscleLab, Langesund, Norway) allows detecting and amplifying internal muscular biological processes. This usually unavailable information is thus made available in a way that is meaningful, rapid, precise and consistent. By use of an encoder, the load displacement in function of the time is recorded. In addition, all derived parameters can be synchronised with four EMG channels. It should be reminded that with MuscleLab is possible to monitor not only the rising of lower of an iso-inertial mass, but also any ballistic motion like jumping or throwing. This is done by use of force plate, timers etc. It means that with the new apparatus, it is possible to measure, record and analyse from single to multiple joint movements. These in turn could be performed in all types of muscular activation: **a)** *concentric,* **b)** *eccentric*, or the combination of both, **c)** *eccentric-concentric* in the so-called stretch-shortening cycle (SSC) performance. SSC represents the most human physical endeavours in the gravitational field. Physiological activities of mammals in the Newton world manifest primarily as movement, spatial displacement or postural maintenance in the gravity field (53). Thus it can be postulated that the earth field of gravity has played a part in the evolutionary development of neuromuscular and motor systems in mammals (67, 82). In light of the above observations, the utilisation of iso-inertial evaluation test represents the most natural assessment that can be performed during both pathologic and physiologic conditions. In this respect, it has been pointed out that the most unbiased monitoring of training occurs when the same regime (same equipment and same movement pattern) is used for both training and testing (64). It should be remind that with MuscleLab it is possible to monitor the muscular activation in the whole range of force-velocity relationship. This is because the system allows the evaluation of muscular behaviour performed through utilisation of loads as external resistance - extremely light or extremely heavy - or anything between (Fig.3).

Some of the advantage of iso-inertial exercise and assessment has been advocated (19,51) to be the following:

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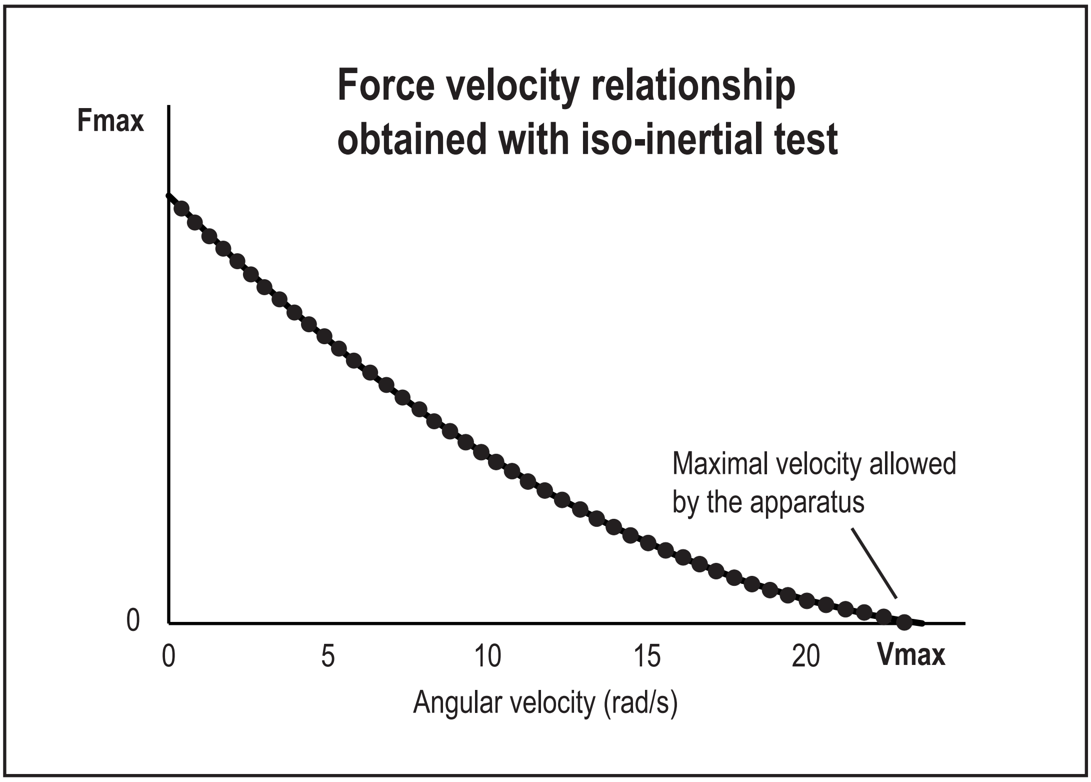

Fig.3.Schematic representation of the force/velocity relationship using iso-inertial apparatus. The apparatus allow the recording of the maximal velocity that can be developed in ballistic motion.

- Gives the possibility to perform also multi-joint assessment.
- Allow the measurement of stretch shortening cycle exercises.
- Both close-kinetic chain and open kinetic chain can be assessed
- Collects quantifiable data for analytic evaluation.
- Allows the examination of muscle output at all range of velocities (1-95 % of Vmax) throughout the movement range. These conditions are more specific to human physical performance than isokinetic or isometric assessments.
- Allow building the force/velocity (F/**V**) relationship (Fig. 3).
- Present high reproducibility (r = 0.85 –0.97) of the tests protocol (e.g. 9, 19, 51).

It is likely that assessment of dynamic characteristics using iso-inertial loads should present few limitations, since is utilised the most natural muscular activity. However if the subjects are not well familiarised with the test to be performed some difficulties can be found. In addition, some disadvantages are claimed (57).

- Amount of resistance limited to weakest point in range of motion. This point is determined by biomechanical characteristics of the joint. Actually these questions are not relevant since we are dealing with a kinetic chain, and in Newtonian physic the weakest ring of the chain determines the strength of a chain. For each muscle or muscle group, during a range of motion there is an optimal condition, which allow the development of the maximum torque. This condition is strongly influenced by the muscle length and the moment arm of the lever around the joint the muscle is acting.

Isometric, isokinetic and/or iso-inertial measurements?

Muscle function can be measured by a variety of methods characterised as the iso-inertial, isokinetic, semi-isokinetic, and isometric testing modalities. Also the type of muscle activity (concentric, eccentric, or isometric) and velocity may vary in testing. In addition more confusion is arising if we are compering various testing methods presented by the literature (44) .The problem is connected to the fact that the assessment of muscle behaviour should be general or specific?

It has been shown that strength and explosive power training had a specific effect on the biological structures stimulated (18, 33, 34). Sale and MacDougal (64), who pointed out that the most important criterion in selecting a test, is specificity, have suggested the pertinent answer to the question. The low relationship between dynamic and isometric tests (e.g. 7, 49 and 50) indicates that muscular measures are specific to the test modality rather than general qualities. The lack of correlation between changes in dynamic performances and isometric test, observed by many authors (e.g. 7, 65, 72, 81), suggests that different mechanisms may underlie the changed performance of these two measures of strength. This would seem to indicate that training induced speed–strength adaptations are also specific. As a consequence of this, testing at a certain speed, or isometric tests, may not be valid for monitoring of the neuromuscular adaptations that are supposed to be induced through dynamic training (e.g.3, 7). There are on the other hand strong indications to suggest that the pattern of motor units recruitment at moderate knee angular velocity is velocity dependent - regardless the muscle activity involved (isokinetic vs. ballistic motion) (17). Finally, it should be remind the effect of pre-stretch cannot be measured properly with isokinetic apparatus. This muscle behaviour is the most natural pattern of human locomotion and can be easily monitored with iso-inertial apparatus.

Neural considerations

As a muscle moves through a range of motion, it has been suggested that there may be preferential recruitment of certain motor units at certain position or angles (22, 70). The neural recruitment pattern observed during isokinetic muscle activation seems to be different to those observed during iso-inertial contraction (Fig. 4). High motor unit activation characterised the beginning of the effort of half-squat exercises. However, as the subjects moved through the range of motion, a parallel decrease of neural activation was noted. The exactly mechanism which caused the reduction of the nervous activation, is not clear. It has been suggested that the high tension required at beginning of motion to overpass the inertial force, may trigger some inhibition from the Golgi Tendon Organs (GTO) (1, 14). In the isokinetic contraction however, the leg extensor muscle maintained the same magnitude of myo-electrical activity along the whole range of motion (25, 37). This is not a surprise finding, since one advantage of the isokinetic exercises is indicated to be the possibility to

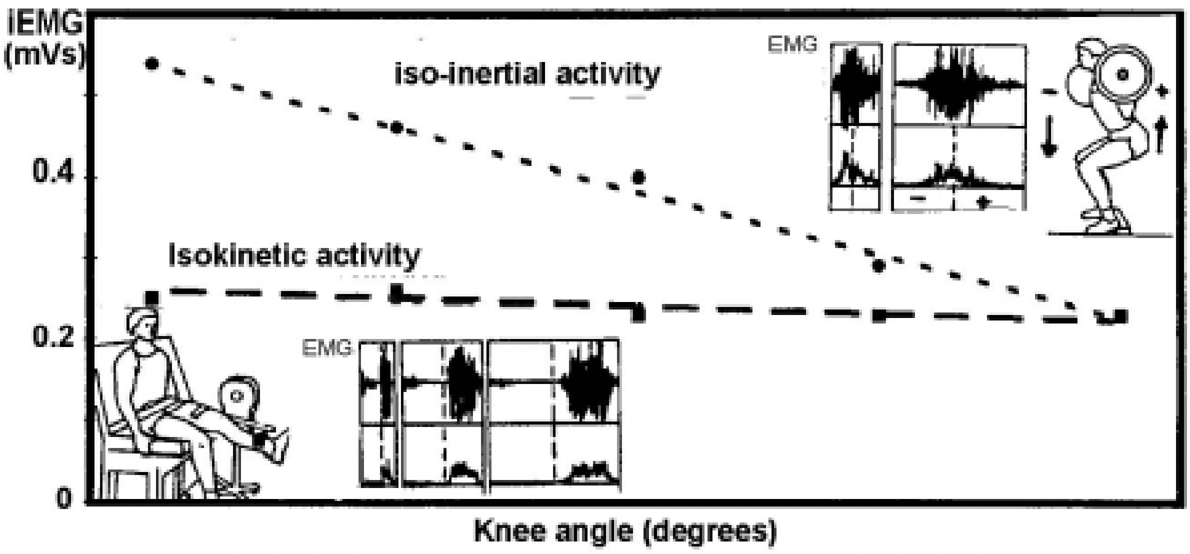

Fig. 4. Electromyografic activity of the leg extensor muscles recorded from the same subjects during an isokinetic tests (squared symbols) and during an iso-inertial tests (half squat performed with an extra loads) (round symbol) of similar external resistance. In the isokinetic evaluation, the EMG activity remained at the same level along the range of movement. In contrast during iso-inertial assessment the EMG activity demonstrated a dramatic burst at beginning of the movement, which was followed by a parallel decrease of neural input as the motion continued to the end (modified from 35 and 46).

maintain maximal nervous activity for the whole range of motion (37). Even if a drastic decrease of EMG occurred at the end of motion in half squat activity, the level was higher than the isokinetic exercise - even if the same external resistance was used. The different structural aspects of the two exercises could also modify the neural recruitment pattern. Hence the force output of the musculature may be affected accordingly. The dynamic squat is often performed with the toes pointing slightly outwards, whilst the isokinetic leg extensor test is performed with the toes pointing straight ahead. It has been shown in other muscle groups that a difference in position affecting the line of pull alters the neural recruitment pattern (71, 75).

Mechanical considerations

Several mechanical factors characterise the behaviour of muscle functions during exercises performed with iso-inertial resistance and in isokinetic condition. Thus, the assessment of the skeletal muscle working capacity is peculiar for the motion executed and thus depending by the tests utilised.

PRE-STRETCH

With iso-inertial method it is possible to utilise the activity of the SSC pattern, while with isokinetic it it is almost impossible to have an effective pre-stretch. This is one factor that strongly differentiates the two assessments. The performance of an eccentric muscular action followed immediately by a concentric action is a common feature of movement executed in the gravitational field. The use of SSC augments the concentric phase of movement, resulting in an increase in work and power (14, 24) and enhanced movement efficiency (15, 23) when compared to similar movement performed without prior stretch. The reported augmentation to concentric action is typically ascribed to the reuse of elastic energy (23, 24) in combination with neural facilitation induced by stretch reflex (16). The effect of pre-stretch depends also by the length of the coupling time, which reflects the transient period between the eccentric and the concentric phases (13). If this transient period is too long (>100 ms), the stored elastic energy can be lost as heat (28). Similarly the facilitation induced by stretch reflex can be lost with long coupling time (11). Thus the length of the transient period, between the eccentric and the concentric phase, is of fundamental importance for the efficacy of SSC. Even if the modern isokinetic dynamometers allow SSC exercises, is rather difficult to note increase of EMG after pre-stretch (69). In fact it is almost impossible to build any electromechanical apparatus which allow reversing the motion from eccentric to concentric in less than 50-100ms. In contrast, in normal motion the coupling time can be in the order of 10 ms, as it occurred in running (39) or in jumping (12). In light of the above considerations, the validity of isokinetic apparatus to monitor muscle behaviour, which in real life situation are almost exclusively performed with SSC, must be called into question. The forces demonstrated always to be dramatically greater when developed under SSC conditions, than those that relied only on the shortening type contraction. The force/velocity curves shifted to the right whenever the concentric contractions followed a pre-stretch activity, like in running or jumping (Fig. 5). Thus during the normal daily activity or during ballistic performances the effect of pre-stretch enhances the force out put in function of the shortening velocity (10).

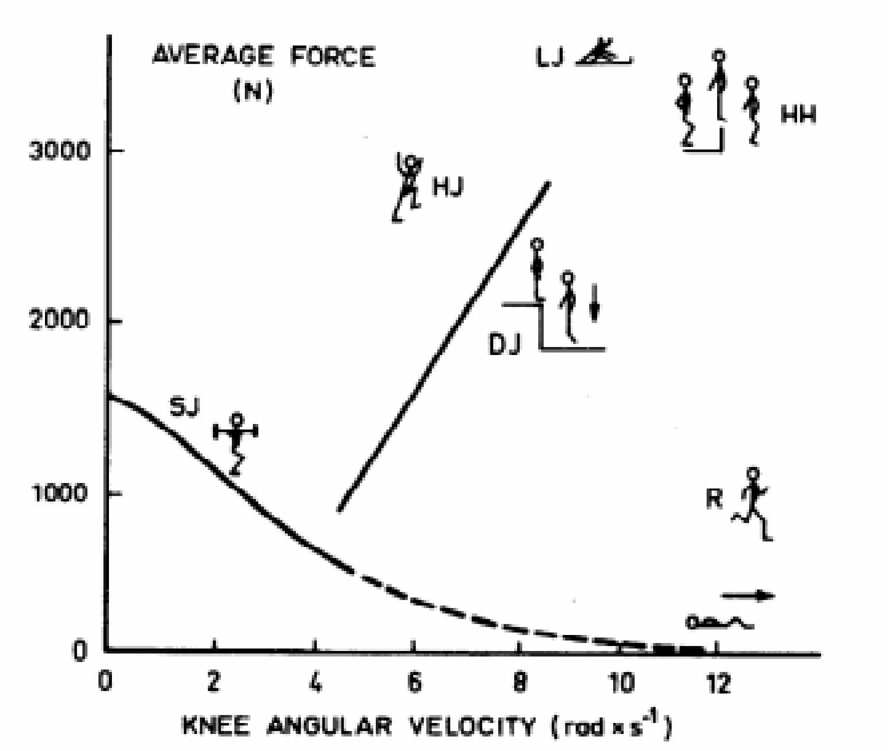

Fig. 5. Force/velocity relationships is presented for two different conditions: vertical jump performed during a simple concentric work (SJ) and after a pre-stretch (DJ). In SJ the force is developed mainly by the contractile component of the muscles, while in DJ the effect of pre-stretch induce a remarkable increase of the force through neural potentiation and re-use of elastic energy. The forces developed during several sport disciplines are also presented in function of the average knee angular velocity: HJ = high jump, LJ = long jump, HH = bouncing over the hurdle, and R = running (modified from 10 and 11).

FORCE VELOCITY RELATIONSHIP

The utilisation of iso-inertial apparatus (19), and isokinetic dynamometer (58), allow building respectively the force/velocity (**F/V)** and torque/velocity (**T/V**) relationships. Both relationships represent a more sophisticated diagnostic assessment of muscle function than isometric test. However, the mechanical behaviour of the skeletal muscle is better described and analysed using the **F/V** than **T/V** relationships. The **F/V** relationship can be described through the recording of several exercises performed with different loads, allowing from 3 up to 100 or even more measurements. Consequently, a dramatic variation of velocity (from 0.5 up to 13 rad/s) can be reached in response to external loads, during leg extensor muscle test (11, 19). Unfortunately, the isokinetic dynamometers allow only few (not more than 8-9) measurements (58), limiting the range of velocity from 0.5 to 5 rad /s. Furthermore, with the iso-inertial measurements, the voluntary effort is modulated by changing both velocity and force (Fig. 6). In the isokinetic test the velocity is already pre-settled by the operator. It is

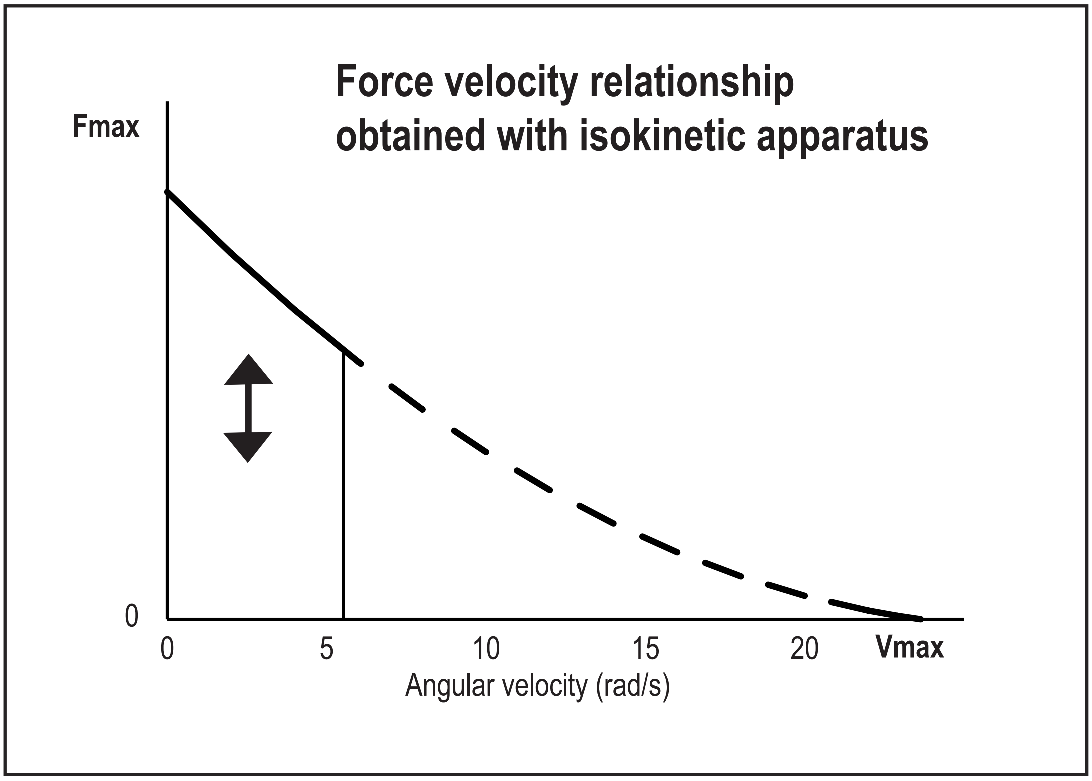

Fig.6. Schematic representation of the of the torque/velocity relationship using isokinetic device. The arrow represents the changes allowed by isokinetic dynamometer, with such devise only the magnitude of the torque can be recorded.

therefore possible to detect only changes in the torque production (Fig. 7). In conclusion, with iso-inertial dynamometer is possible to analyse and discriminate the muscle tension developed against low or high external resistance, while with isokinetic test only high resistance is allowed to be measured.

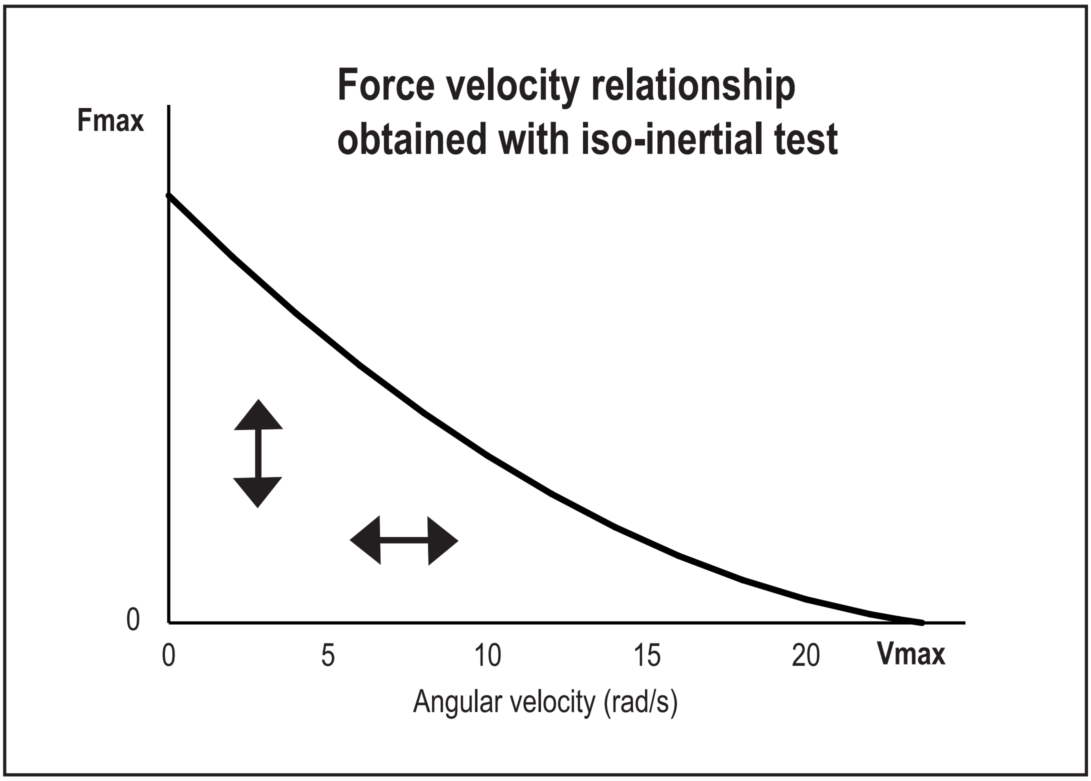

Fig.7. Schematic representation of the of the force/velocity relationship obtained with iso-inertial load device. The arrow represents the physiological variable that can be detected and recorded with the dynamometer. Note that both speed and force can be varied in function of the effort performed.

Assessment of muscle strength or pain tolerance

Muscle function or pain threshold

The athlete with any type of injury should return to activity quickly and safely with appropriate surgery, treatment and rehabilitation. The rehabilitation programme should emphasise decreasing inflammation, restoring motion, increasing strength, and safe return to competition. This can begin pre-operatively and progress post-operatively through a programmed treatment and intervention protocol supported by a functional evaluation and clinical diagnosis of muscular behaviour. Since the last phase of the rehabilitation programme of an athlete usually involves isokinetic training, most of the muscular evaluation assessments have been performed with isokinetic apparatus. Unfortunately such evaluation system present a strong and dramatic limitation. The evaluation of the maximal-torque capacity in both pre-operative and post-operative conditions requires that the patient/athlete develops at least of 60% of the maximal strength. This applies even at the highest speed allowed by the isokinetic apparatus. This high level of muscle tension does not represent the full neuromuscular behaviour, but is strongly influenced by the pain threshold. Thus, during an evaluation assessment, high force is required and a tension limiting mechanism may occur. Consequently, it is likely that the strength output is the result of many factors, including pain sensibility, reduction of neural drive, the effects of disuse and immobility on musculo-skeletal tissues. It has been suggested that during eccentric load conditions, joint kinaesthetic receptors of a Golgi type (68), free nerve endings in the muscle, cutaneous receptors and joint receptors could also participate in the reduction of neural drive (79). This tension-regulating mechanism would contribute to the limitation of muscle tension and preservation of muscle integrity, not only during eccentric work, but also during injury and in the postoperative conditions. This means that the true maximal effort and the output of maximal force depend on individual pain threshold. Thus the measured torque does not reflect the true muscle function, but also the ability of the patient to stand the pain.

Assessment of muscle function using light loads

In light of the above observations, the iso-inertial assessment test that allows the measurement of muscle function against very light loads, seems to be the most appropriate evaluation system. In fact, in both pre- and post-operative conditions, it could be possible to measure the muscular behaviour using only light loads (e.g. 1-5 % of maximal strength). Therefore the development of low force at high speed may avoid the negative influence induced by pain and eliminate the intervention of the tension regulating mechanism. The iso-inertial dynamometer can be utilised for evaluation of both CKC and OKC to assess a patient’s strength and readiness to progresses to higher functional level. CKC evaluation tests have been promoted as more functional, appropriate and safer than OKC tests. But with the iso-inertial load dynamometer it is possible to safely measure in the post–operative conditions (surgery of anterior cruciate ligament “ACL “) the functions of skeletal muscles group during OKC. In this respect MuscleLab was used to assess and calculate the power developed during leg extension exercises using as external resistance only 5 kg. The measurements from a basketball female and volleyball female players, collected after two and fifty weeks respectively after ACL surgery, are shown in Fig. 8 and 9. The iso-inertial apparatus allowed detecting a dramatic loss of power (220 %) for the basketball player (182 vs 82 watts, non vs

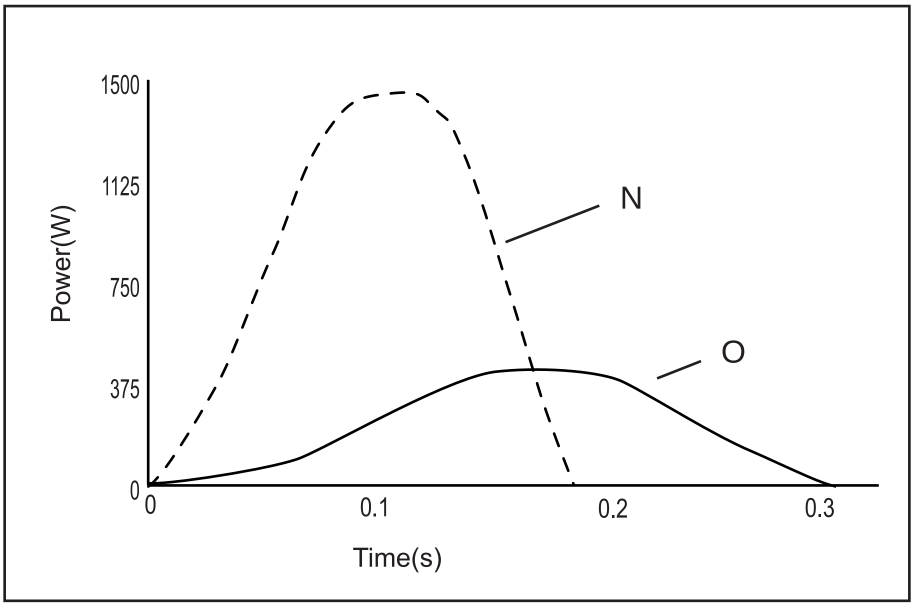

Fig.8 . Power developed during leg extension exercises performed, by female basketball player , with total load of 10 kg (included the weight estimated for the thigh), is presented in function of the time. The operated leg (O) demonstrated lower power requiring longer time for the its development compared to the other leg (N).

operated leg). In the volleyball player a strong rapid recovery was noted in the post surgery period. In fact the power developed was 195 vs. 166 watts respectively for non and operated leg. The EMGrms in the mm vastus lateralis and medialis of both legs were recorded simultaneously with leg extension power measurements. This showed that for the operated leg of the basketball athlete the low power output was related to low EMG activity (only 27 % of the non-operated leg). These results indicated the occurrence of strong neural drive inhibition (e.g. 26). In contrast, the operated leg of the volleyball athlete demonstrated neuromuscular efficiency. In fact the EMG activity of the operated was 200 % higher than the not operated leg. The power output showed only a modest reduction (17 %) compared to not surged leg. In light of these results the treatment for a more specific rehabilitation programme could be facilitated. Although, those measurements were performed with OKC, it could be possible as well to use CKC. Exercises performed on leg press, or any other similar machine that utilise as external resistance gravitational load, or during no bearing loads like squat or squat jump, can be monitored with MuscleLab. The latter test exercises have been recently emphasised in the international literature to be a more functional test that could be used for assessment of muscle behaviour in rehabilitation field (5, 30, 54)

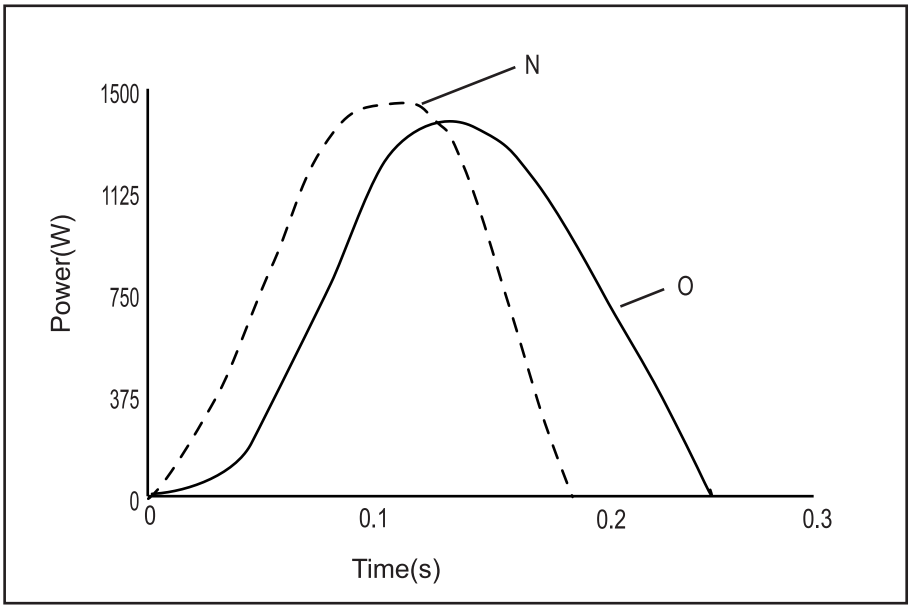

Fig.9. Power developed during leg extension measurements performed by female volleyball player, with total load of 10 kg (included the weight estimated for the thigh), is presented in function of the time. The operated leg (O) demonstrated lower power compared to the other leg (N).

The effect of vibration on EMGrms activity of skeletal muscle

The assessment of the neuromuscular behaviour has received in the last decades a strong improvement through the evolution of diagnostic technique. This was allowed by the creation of new dedicated instruments and apparatus that have been used mainly in the field of rehabilitation and sport medicine. However, the assessment of the neuromuscular functions is steel far to be enough complete for covering the large spectrum of biological changes which occurs with injures and after surgery. In fact, there is an high percentage of patients showing a weakness of the leg extensor muscles after a long follow-up period - most likely due to the severing of propioceptors during surgery (27). Even if such problems are well known there is an inadequate and lack of specific evaluation technique that could allow the quantification and assessment of the impairment due to the proprioceptors inability to function properly. In this respect, it was conduced a pilot investigation to analyse the possibility for detecting and quantifying the operated knee joint propioceptors functional capacity. For this purpose a new diagnostic technique, consisting on monitoring the muscles EMGrms activity during vibration, was applied for identify altered neural strategies of motoneuron pool recruitment. Previous findings of EMGrms recorded in biceps brachii of boxers (20), showed a significant enhancement ($P<0.001$) of the neural activity during the vibration treatment period, as compared to normal conditions. Similar results have been noted monitoring the EMG activity of the leg extensor muscles (mm. vastus lateralis: LL (left) and LR (right) and vastus medialis: ML and MR), of an healthy athlete during a vibration treatment period (Fig. 10). Facilitation of the excitability of spinal reflex has been elicited through vibration to quadriceps muscle (21). It was suggested previously the possibility that vibration may elicit excitatory inflow through muscle spindle – alpha motoneurons connections in the overall motoneuron inflow (47). It has been demonstrated that vibration drives alpha - motoneurons via Ia loop producing force without descending motor drive (61). In addition, it has been shown that vibration-induced activation of muscle spindle receptors, not only in the muscle to which vibration was applied, but also to the neighbouring muscles (43). Mechanical vibration (10-200 Hz) applied to muscle belly or tendon can elicit reflex contraction (31). This response has been named " tonic vibration reflex " (TVR). It has been also argued that in the presence of TVR, the vibration-induced suppression of motor output in maximal voluntary contractions probably does not depend to the voluntary command

(6). It was suggested that contributing mechanism might be vibration induced pre-synaptic inhibition and/or transmitter depletion in the group Ia exitatory pathways which constitute the afferent link of the gamma-loop (6). In light of the above findings, a pilot study was planned to introduce a new assessment strategy to identify muscle behaviour and possibly dysfunction.

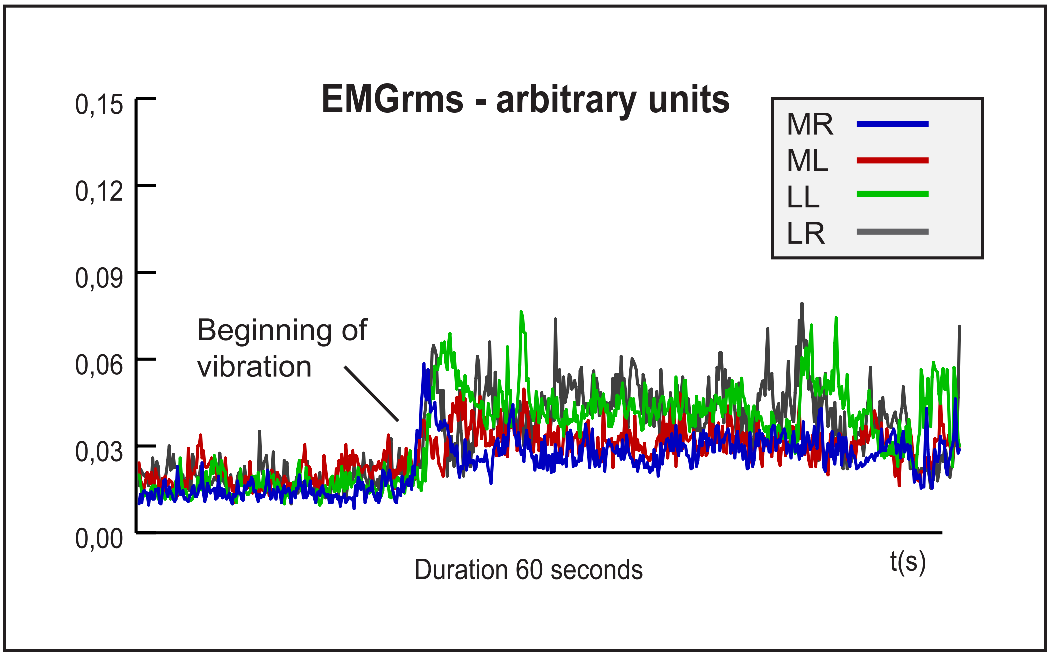

Fig. 10 . Electromyografic activity (EMGrms) recorded from leg extensor muscles (mm. vastus lateralis : LR and LL and medialis : MR and ML of both left and right legs) , before and during whole vibration treatment . During the vibration treatment a remarkable enhancement of the EMGrms was recored

EMG analysis and vibration for assessment of propioceptors functions

To evaluate the proprioceptors capacity to function properly several subjects who have been previously (at lest one year before) operated in one leg, were exposed to vertical sinusoidal whole body vibration (WBV) for 60s. During the vibration treatment the EMGrms activity of leg extensor muscles leg extensor muscles (mm. vastus lateralis: LL (left) and LR (right) and vastus medialis: ML and MR) were simultaneously monitored in both normal and operated legs. The subjects stand in semi-squat position (knee angle at 90°) on a vibration platform (Nemes ® – Bosco System), while the frequency of vibration was settled around 40 Hz for a total period of 60s (Figures 11 and 12). When the EMGrms of the post-operated leg was compared with the healthy one, remarkable higher activity could be observed in the post-operated leg during vibration treatment .A statistical analysis revealed that the EMGrms activity of the post-operated leg was significantly higher than the counterpart leg (Fig. 13). Since it is likely that during a surgery a severing of proprioecpetors may occurred, it is therefore tempted to

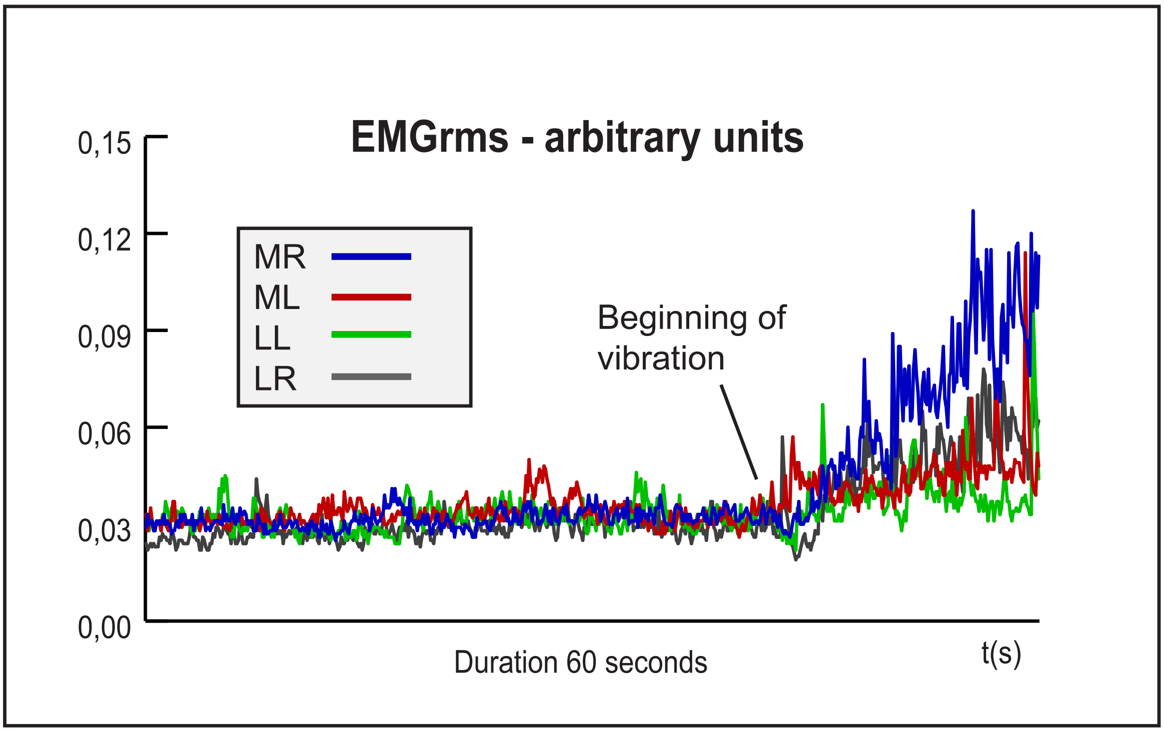

Fig. 11 . Electromyografic activity (EMGrms) recorded from leg extensor muscles of a male athlete (mm. vastus lateralis :LR and LL and medialis: MR and ML of both left and right legs), before and during vibration treatment .During the vibration period higher EMG activity was noted in both legs compared to normal conditions. However a remarkable enhancement of the EMGrms was noted in the post-operated leg (VLR and VMR) compered to healthy one

suggest that the high EMG activity noted in the operated leg might be caused by the inappropriate function of propioceptors. It is likely that among the functional capacity of the propioceptors, is filtering and modulate the neural drive from central command. If the propioceptors were severed during surgery (27), this filter capacity of the neural drive could therefore be lost - resulting in hyperactivity during vibration treatment. Although it is not easy task to find a proper explanation, these findings could be utilised to detect the function of propioceptors. It should be noted that 100% of the subjects studied (eighteen), demonstrated higher EMG activity in response to vibration in the muscles of the leg operated compered with the controlateral healthy leg. These findings suggested that before a rehabilitation programme can claim to be successful, the assessment of the muscle functions described only by the mechanical evaluation of the force or torque output is not physiologically enough. There is steel an inadequate and lack of specific evaluation technique that could allow the assessment of the impairment due to the proprioceptors inability to function properly or not.

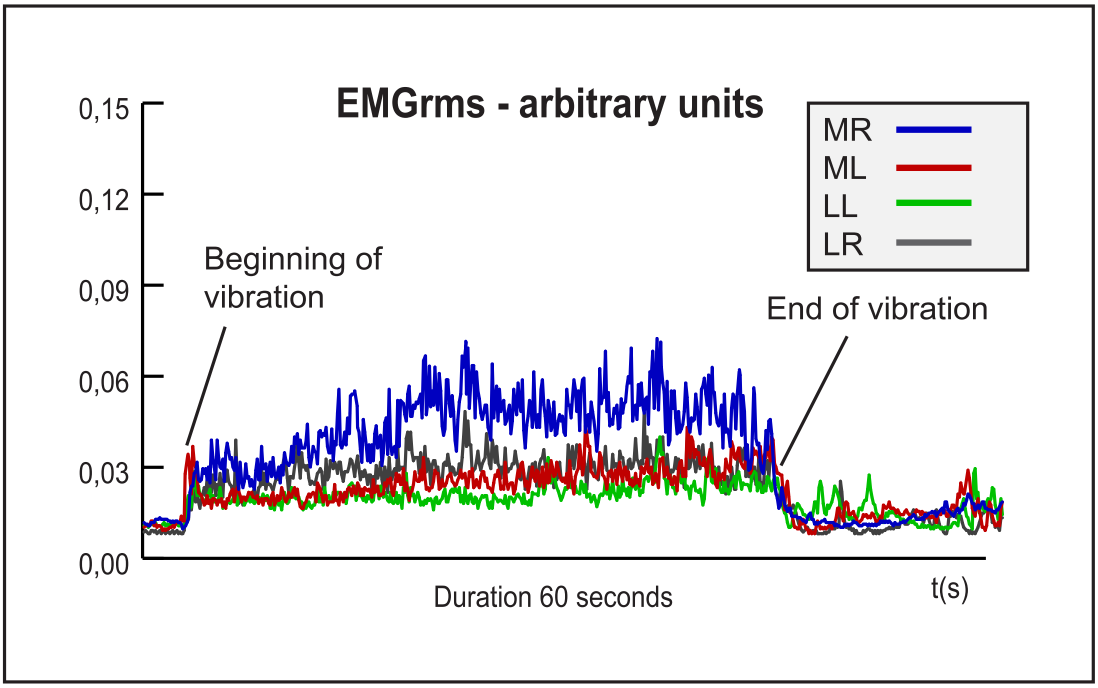

Fig. 12 . Electromyografic activity (EMGrms) recorded from leg extensor muscles of a female athlete (mm. vastus lateralis: LR and LL and medialis: MR and ML of both left and right legs), before and during vibration treatment. During the administration of vibration, higher EMG activity was noted in both legs. However a remarkable enhancement of the EMGrms was noted in the post-operated leg (LR and MR), compared to healthy one.

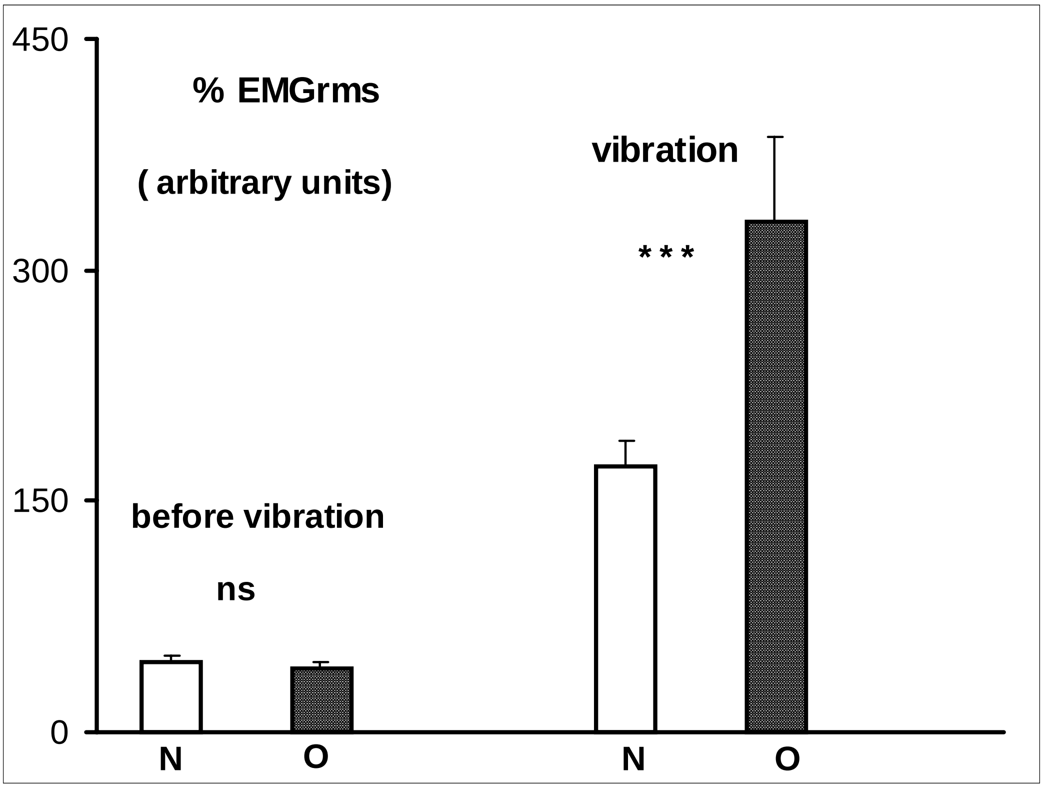

Fig.13. Mean (±SE) of the electromyogram root-mean square (EMGrms) given as percentage of baseline (100 %) recorded from mm. vastus lateralis and medialis in both non-operated (N) and operated (O) legs of eighteen subjects - before and during vibration treatment. No statistical significant difference was observed between N and O before vibration treatment (ns). But during vibration the O legs demonstrated statistical significant difference with the N legs, $P<0,002$; (Student's t- test for paired observations).

New diagnostic method for prediction of hamstring injures

Hamstring strains are among the most common injuries (and re-injuries) in athletes. Hamstring muscle tear takes place during eccentric exercise when the muscle develops tension while lengthening. To determine the relation of hamstring and quadriceps muscle strength and imbalance to hamstring injury isokinetic, strength test usually has been utilised (57). It is generally thought that to prevent hamstring injures, the H/Q ratio assessed with isokinetic device, should not be less than 60 %. Unfortunately this is only a poor evaluation to predict possible hamstring injures. In fact the strength assessment performed with constant speed device operated at low speed (3-4 rad/s) cannot be compared with the force developed during eccentric work at extremely high speed (14). In this connection it has been noted that isokinetic strength testing does not predict hamstring injury in athletes (4).

In light of the above observations it was introduced a new functional test which allow to assess the leg extensor muscle functions during ballistic motion like vertical jump. During a vertical jump performed from half squat position, hamstring and quadriceps co-contraction has been documented and explained via a co-contraction hypothesis. This hypothesis provide a stabilising force at the knee by producing a posteriorly – directed force on the tibia to counteract the anterior tibial force imparted by quadriceps. EMGrms was recorded from right and left hamstring (HR, HL) and left rectus femoris (RFL) in order to determine muscle recruitment patterns of knee extensor and flexor. In fig. 14 are presented an example of a female sprinter, revealing the both RFL and HL were strongly engaged during vertical push off while the HR demonstrated only moderate activity at the end of the push off. The high activity noted in the HL was associated with a previously hamstring injury. On the other hand the HR showed low level of activity. This is reflecting the low demand placed on the hamstring muscle to counter anterior shear force acting at the proximal tibia. These altered neural strategies reflect changes in neural inputs to the motoneuron pools that will be recruited in generation a specific motor task. To try to detect possible dysfunction it was compared the EMGrms activity of Q with H. Preliminary results revealed that when the EMGrms ratio Q/H is more than 1, no problems could be noted in the hamstring. On the other hand if the ratio was lower than 1, some symptom of hamstring injury was claimed by the athletes. Similar procedure have been suggested recently to assess muscle dysfunction (26)

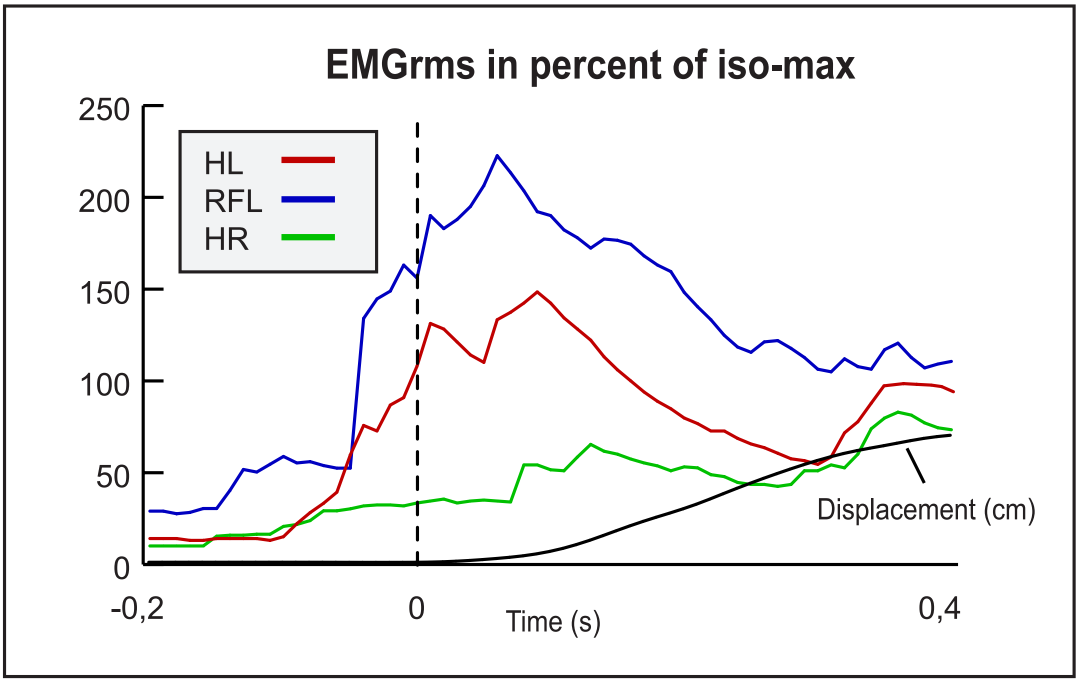

Fig. 14. Electromyogram root-mean square (EMGrms) recorded in the hamstring left (HL) and right (HR) and rectus femoris left (RFL) from a female sprinter during vertical jump performance. In the figure is shown also the displacement in cm during the push of the jump. The high activation of the HL was connected to the claim of problems felt by the athlete in the left hamstring.

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