IMPORTANCE OF PROPRIOCEPTIVE ACTIVATION ON FUNCTIONAL NEURO-MUSCULAR PROPERTIES

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Neuromuscular adaptation following strength training has been widely discussed in the literature. There is common consent that alterations in maximum voluntary contraction can be achieved either by muscular hypertrophic effects or by improvements in neuronal supply of the muscle. Both aspects address primarily the contribution of the efferent part of activation. For combination of muscular action, i.e. for the stretch-shortening cycle, the role of the afferent activation rocesses has been demonstrated. However, the question whether afferent contribution may also modulate the strength development in voluntary contractions has not been discussed in detail. Data are presented that emphasise the concept that, induced by proprioceptive training, the improvement in afferent sensitivity are in close relation to improvements in the capacity of the neuromuscular system for explosive power. Functional considerations are given with respect to rehabilitation and to adaptation in athletic strength training.

KEY WORDS: neuromuscular adaptation, proprioceptive training, explosive power

INTRODUCTION: In strength training it has been shown that adaptation processes of the neuro-muscular system may be attributed to mechanisms based on either neuronal or muscular aspects (Sale 1992). It is well agreed that the force capability of maximum voluntary contraction (MVC) is largely dependent on the cross sectional area of the muscle and that recruitment and firing rate of the active motoneurons determine the rate of force development (RFD) (Enoka&Fuglevand, 1993).

For strength adaptation most of the papers are related to the training induced changes in the basic strength of the maximum voluntary contraction (Garfinkel and Cafarelli 1992; Jones and Rutherford 1987; Häkkinen and Komi1986), only few approaches are investigating systematically the mechanisms underlying the alterations in the rate of force development.

Efferent and afferent contributions are determining the actual excitation of the motoneuron system. For strength training the efferent, voluntary controlled activation has been addressed to be responsible for neuronal adaptation in various training studies. The precise role of afferent contributions has been speculated primarily for a specific type of muscular action, the stretch-shortening cycle (Gollhofer, 1987; Komi, 1984).

In the present contribution the various possibilities of neuronal adaptation in strength training is addressed. Based on the potential possibilities of reflex induced activation in plyometric activities a training study is presented. Here, the combination of afferent and efferent activation processes is systematically trained on the basis of a proprioceptive training exercise. The final part concentrates on the problem to what extend the adaptations of afferent system may also influence voluntary muscular actions.

Afferent contribution in stretch-shortening cycle. Recent research work was concentrated on the activation characteristics in the natural combination of muscular action – in the stretch-shortening cycle (SSC). For those types the functional importance of stretch reflex activation has been controversially discussed (Van Ingen Schenau 1997). Extensive literature provides evidence that stretch reflexes modulate the stiffness of the tendomuscular system in reactive and plyometric conditions. Both animal and human experiments were conducted to show whether afferent contribution in natural movement (i. e. locomotion) enhance the performance capability, especially when the system acts in the SSC (Gregor et al., 1988; Komi and Gollhofer, 1997). Although it is not possible in natural human movement to separate methodologically afferent from efferent activation contributions, it has been argued that basically monosynaptic reflex activities contribute in SSC (see figure1). Efficient stretch reflex contribution may be expected when the extensors are activated prior to the stretching phase after contact which is necessary to enlarge the range of short elastic stiffness, thus linearising the stress-strain characteristics of the tendomuscular system

(Nichols 1987; Houk and Rhymer 1981). Functionally these afferent contributions are necessary to compensate yield in the early impact phase and thus enhance the power output for the subsequent push-out phase. The reflex contribution, however, is highly sensitive to loading conditions (Gollhofer et al. 1992) (see also Figure 1).

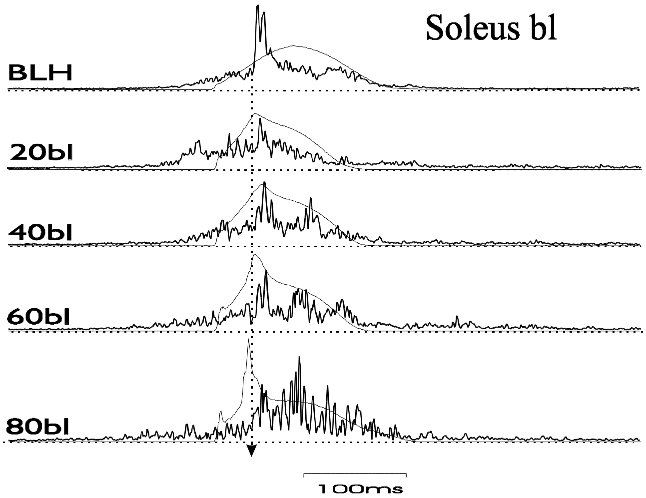

Figure 1 - EMG-Pattern of M. Soleus and vertical ground reaction force in drop jumps with increased stretch load.
(from top: BLH-both leg hopping, 20bl .. 80bl – Drop jumps from 20 .. 80 cm height. The vertical line indicates the instant 40 ms after touching the force plates. 40ms after touch down, basically monosynaptic reflex contribution may be expected)

As the drop jump height is increased the amplitude of the reflex component is reduced suggesting a decreased reflex facilitation. This reduction has been interpreted to serve as a protection strategy to prevent excessive loading of the tendo-muscular complex. Thus, stretch reflexes may make a net contribution to muscle stiffness already during the eccentric part of the SSC. It is difficult to imagine that proprioceptive reflexes, the existence of which has been known for centuries, would not play any significant role in human locomotion including SSCs.

Proprioceptive training as a model to exercise afferent activation contributions. Theoretically promoted as proprioceptive facilitation of the neuronal contribution of the various receptor types in the joint complexes, in the tendon and in the muscular structures, proprioceptive training is frequently applied in rehabilitation. Similar to the argumentation in SSC, this type of training aims to improve the efficacy of the afferent contribution in the neuromuscular control, in order to attain better limb control and to achieve an early access to the muscles encompassing joint complexes. However, no controlled studies are available that demonstrate whether proprioceptive training improve the afferent contribution in general. Thus, in a series of experiments we have investigated the effects of proprioceptive training interventions on the neuromuscular properties. Specific emphasise was given to the evaluation of afferent and efferent alterations. Additionally, it may be expected that augmentation of afferent input to the muscle should have also positive effects in the activation process under MVC conditions.

METHODS AND MATERIAL: Three experimental groups performed for 4 weeks (4 times*week^{-1}) a specifically designed proprioceptive training program. The training regimen consisted in postural exercises on tilt platforms or ankle pad (AIREX). The subjects (n=65) were instructed to perform all exercises as one-leg stance stabilisation tasks. In order to differentiate the effects group1 (barefoot) exercised barefoot, group2 (AIRCAST®) with a semirigid ankle fixation and group3 (skiboot) trained with fixed ankle joint. The rational for this selection was to separate the training effects according to the number of allowed degrees of freedom: The barefoot group was allowed to perform freely both the ankle and knee joint systems, whereas the skiboot group had to perform with mechanically blocked ankle systems.

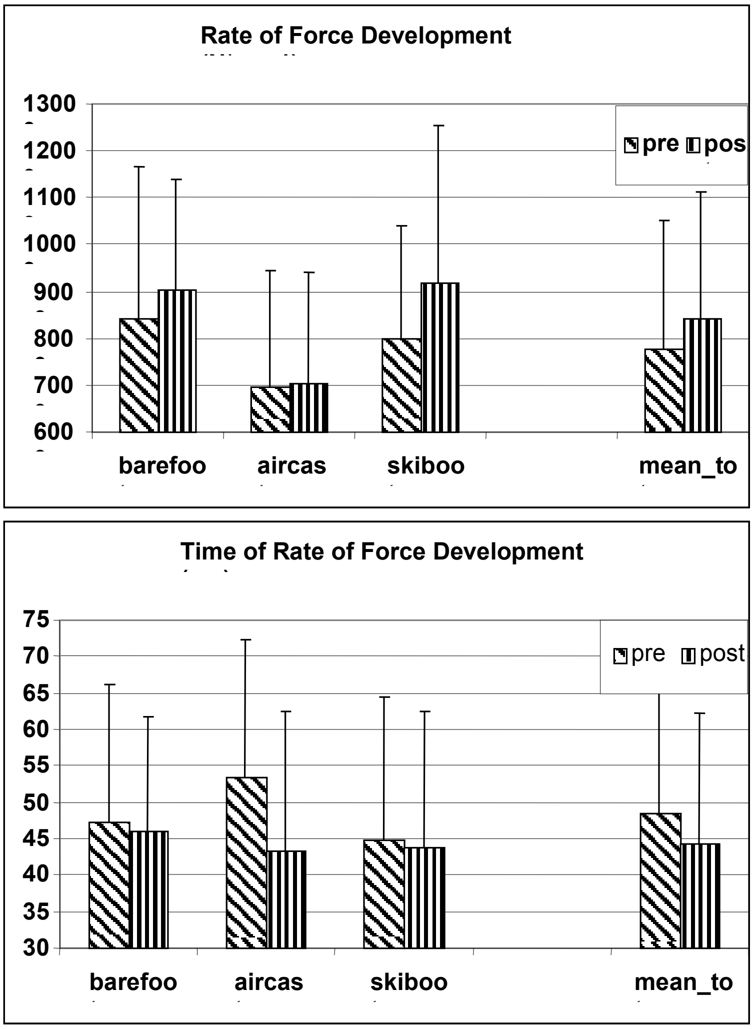

Figure 2 - Mean values of the time to reach maximum rate of force development (RFD) in the isometric leg extension (upper part); mean values of the maximum RFD (lower part).

Pre and post measurements comprised force examinations of the leg extension, postural stabilisation on a two-dimensional platform (POSTUROMED(®)), functional knee joint stiffness as well as inversion movements on a platform system. Tilt movements were designed to produce an unexpected valgus stress at the knee joint. The functional knee joint stiffness was assessed by a specifically designed apparatus that allowed to induce a mechanical displacement at the tibia relative to the thigh. Subjects were in the upright stance and loaded their legs equally. This mechanical stress produced an anterior drawer at the knee joint under functional, i.e. axial loaded conditions. Quantification of the mechanical parameters of the anterior drawer and determination of the neuronal response allows a comprehensive examination of the functional status of the knee joint complex (Bruhn 1999).

Electromyographic activation was recorded from ankle and knee joint muscles: M. Gastrocnemius m. ; M. Tibialis a.; M. Peronaeus l.; M. Vastus m.; M. Semitendinosus m.. By means of twin-axis goniometers (PENNY&GILES(®)) the angular excursion in the ankle and knee joints was registered together with the relative torque between shank and thigh movement. All signals were A/D converted (1000 Hz) and stored on a PC for off-line analysis.

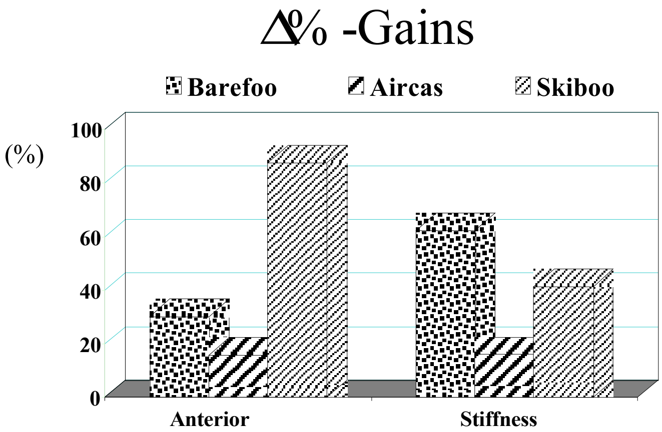

Figure 3 - Training induced reductions of the anterior drawer and improvements of stiffness in the knee joint following mechanical displacement. The bars denote the mean values of the three experimental groups.

RESULTS: The EMG of the ankle joint muscles did not reveal statistical significance in the evaluation of the training effects. However, there was a significantly higher EMG activation for the skiboot group for the knee joint muscles. In all three training groups only small

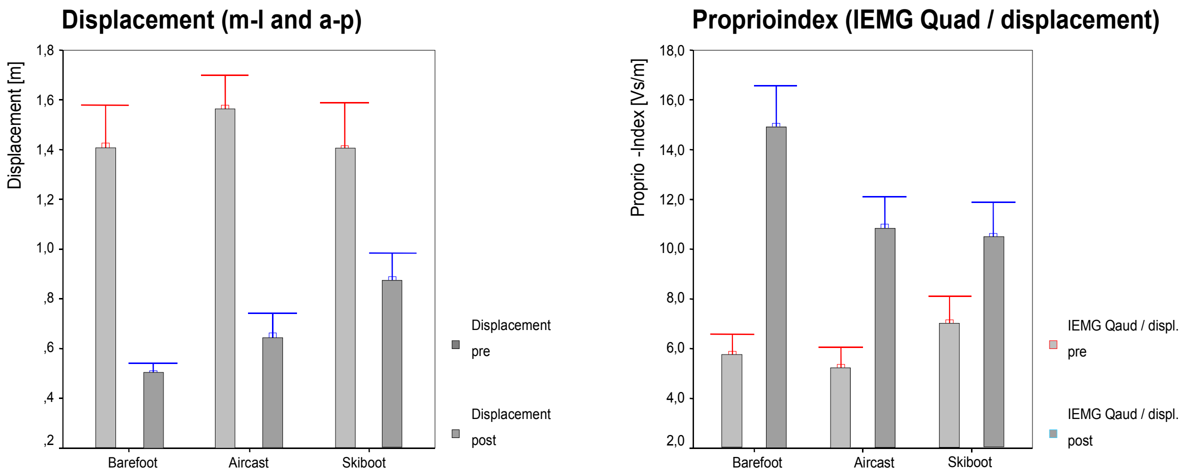

Figure 4 - Pre/Post-Differences of the displacement in medio-lateral-direction and in anterior-posterior direction while the subjects performed free stance stabilisation on a 2-dim unstable platform for 40 secs (left part). Pre/post-Differences of the proprioceptive index, calculated as the ratio of displacement and integrated EMG (IEMG) of the quadriceps muscles (right part).

improvements in the leg extension force could be observed. However, the time to reach RFD was reduced while the mean rate of force development (RFD) was enhanced (Figure 2).
In functional knee examination the anterior-posterior drawer was diminished (Figure 3) most pronounced in the skiboot group. The stiffness of the knee joint complex, determined as the ratio of induced drawer force and the resultant anterior drawer, was enhanced in all three groups by approximately 20 to 60% in the before/after comparison.
In the stance stabilising test the subjects were asked to maintain equilibrium while standing on one leg for 40 sec on the two-dimensional unstable platform. Post training, the physical ability to stabilise in the upright stance was increased in all subgroups: Both medio-lateral component as well as anterio-posterior displacement of the integrated platform movement was drastically decreased. In line with these reductions the IEMG values of the ankle and knee joint muscles were diminished, respectively. However, the ratio ”displacement necessary for stabilisation divided by IEMG” was enhanced, both for the quadriceps muscle as well as for the hamstring muscles. Thus, the proprioceptive function expressed as the IEMG per sway was increased significantly in all three training groups.

DISCUSSION: Despite the fact that proprioceptive training has loaded the knee joint muscles during training differentially, the functional adaptations were quite similar in all training groups. The mechanical stiffness of the joint complexes was increased, concomitant with a significantly enhanced proprioceptive control during dynamic stabilisation. In-line with these findings the capability to produce the maximum rate of force development in shorter time was improved.
In previous studies on proprioceptive adaptation it has been observed that training induced proprioceptive gains in monosynaptic reflex behaviour are correlated with the improvements in explosive strength: Subjects who performed in a four week training program designed for proprioceptive joint stabilisation enhanced their capability for explosive strength significantly compared to subjects who exercised pure isometric and concentric muscular performances. The group with the largest improvement in explosive strength showed the greatest gain in reflex contributions.

High frequency intermuscular coordination, a reflex controlled mechanism in dynamic stabilisation. The mechanical importance of improvements in the proprioceptive gain reflects the changed ability of the neuromuscular system to activate the muscles more efficiently at the onset of force development (Dietz et al. 1987). From a functional point of

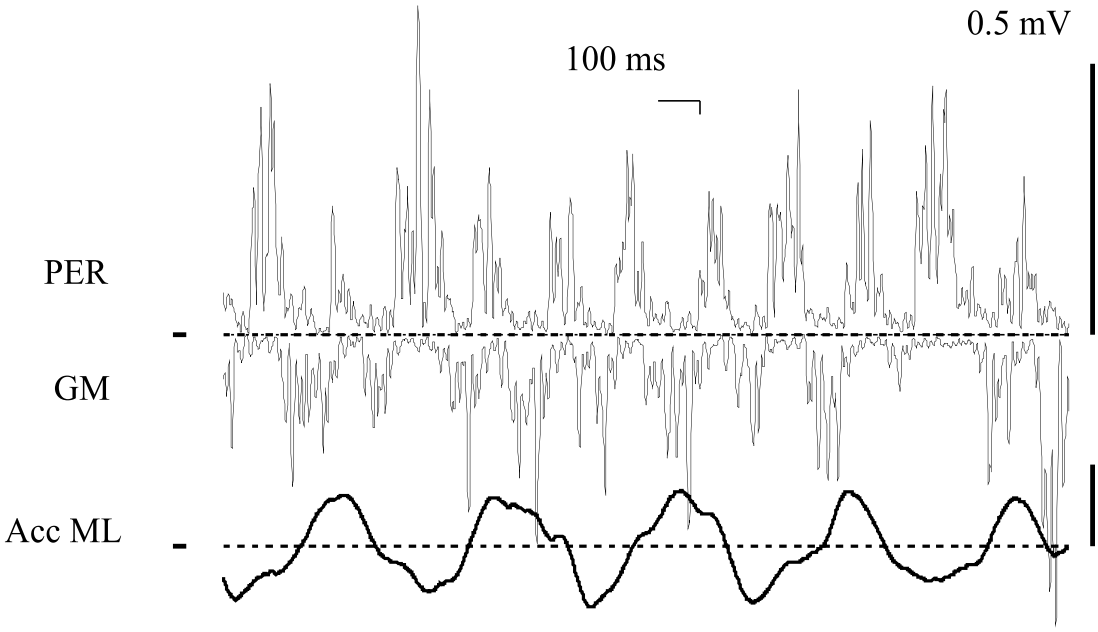

Figure 5 - EMG Profile of Peroneus (PER) and Gastrocnemius (GM) muscle together with the medio-lateral component of the accelerometer signal (ACC ML) in a posture task on an unstable platform. The distinct bursts in the emg patterns occur with a frequency of about 8 Hz.

view quicker access to the muscle may be important in order to stiffen joint complexes in disturbance conditions. In rehabilitation, proprioceptive training programs are employed to ”teach” the agonist/antagonist muscles to stabilize a joint complex actively.
In order to verify this hypothesis a detailled electrophysiological analysis of the emg profiles in dynamic stabilisation control was performed. As an example the EMG patterns of one subject are depicted in Figure 5. Obviously, the dynamic stabilisation task requires quick regulations in the muscular activation. This control is achieved by fast neuronal interactions of agonist and antagonist activation with high intermuscular frequency. The pattern of this neuronal communication consists of phasic bursts interacting with a frequency up to 8 Hz.
Role of Ia-afferents in the isometric force development. Macefield et al. (1991) demonstrated that the discharge rate is drastically reduced in isometric conditions when the afferent contributions are withdrawn. On the basis of frequency analysis on single motoneuron discharge rates they concluded that intact afferentation provides for adequate

fusimotor drive. Higher discharge frequencies, however, are responsible for faster rates of force development of the motoneuron. Based on H-reflex data obtained in ramp contraction, several observations favour the hypothesis that afferent reflex contribution has also a gating effect on isometric strength development (Meunier/Pierrot-Designy, 1989). Comparing different ramp velocities and various levels of voluntary contraction (MVC) evidence exists that the sensitivity of the motoneuron pool is highest in the early phase of typically fast ramp velocities performed with high MVC percentages.
The results from proprioceptive adaptations emphasise the idea that based on these high frequencies and on the highly specific intermuscular coordination seen in postural performances (Figure 5) it is most likely that the neuromuscular activation observed in joint stabilisation task is generated by reflex activation (Dietz and Noth 1978). As the frequency of the observed intermuscular pattern is too high to assume regulation via central pathways, their control mechanisms must be assumed to be on the spinal level.

CONCLUSION: The mechanical importance of enhanced afferent gains in the neuromuscular control seems to reflect the changed ability of the neuromuscular system to activate the muscles more efficiently at the onset of force development. Especially in disturbance conditions quicker access to the muscles my be important to stiffen joint complexes. Not only in rehabilitation, even more pronounced in athletic training, i.e. in alpine skiing, proprioceptive training programs may be an efficient tool to improve the agonist/antagonist intermuscular communication. This may have functional importance in all sport disciplines with explosive power demands.
From a physiological point of view, muscle spindle afferents are not simply stereotype responses to unexpected stretches. Embedded in the neuromuscular pattern they provide high stiffness in the tendomuscular system, not only in the SSC. Moreover, they are highly efficient in the isometric force development.

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