First publ. in : European journal of sports traumatology and related research ; 23 (2001), 2. - S. 82-89

# Proprioception training for prevention and rehabilitation of knee joint injuries

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*SUMMARY. S. Bruhn, A. Gollhofer, and M. Gruber:* ***Proprioception training for prevention and rehabilitation of knee joint injuries.*** *Eur. J. Sports Traumatol. rel. res. 23: 82-89, 2001. The purpose of this study was to evaluate the effects after 4-week proprioception training on functional stability of the knee joint and on the inter- and intramuscular coordination. In order to estimate the coordinative abilities and the stability of the knee joint, data were collected in 4 different experimental set-ups. Postural stability in static and dynamic form, the maximal voluntary isometric contraction of the knee joint musculature, and reflex contributions in simulations of injury mechanisms were determined. As a consequence of the 4-week training program, the sensorimotor characteristics of the knee joint complex were improved. Postural stability determined on an unstable platform was significantly enhanced, both in mechanical as well as in neuromuscular parameters. Improvements of the isometric rate of force development were closely related to the gains in activation of the involved muscles. Functional stability determined as joint stiffness and EMG activation following a mechanically induced anterior tibial displacement was significantly enhanced. The results of the study suggest that this type of training is powerful enough to improve both functional stability of the knee joint complex and movement coordination.*

## INTRODUCTION

From a technical point of view, the existence of intra- and intermuscular coordination can be interpreted as a complex interaction of sensorimotor control and regulation processes for the adjustment of task-specific and situation-adequate stiffness of the entire joint complex.

There is a clear agreement that the neuromuscular system utilises the afferent contribution of sensory receptors e.g. proprioceptors, which feed back information from the periphery of the limbs to the spinal cord and higher stages of central integration (1). Within the spinal cord, information from various sources converges in spinal interneuronal centres. Together with centrally generated activation programs, the task specific activation is transferred to the motoneurons ensuring a balanced control of limb stiffness and force generation (2, 3).

On the one hand, coordinated movements are a necessary prerequisite for maximum performance output. On the other hand, a possible incidence of injury is associated by a lack of movement coordination. In connection with fatigue, minor coordination can be regarded as one of the major injury risks even within a distinct performance level.

The evolution from quadrupedal to bipedal gait is associated with an increased loading of the joints of the lower extremity. The knee joint in particular, interposed between the two long levers of femur and tibia, presents a higher risk to injury and degenerative disease. Especially, ruptures of the anterior cruciate ligament are one of the most disabling knee injuries for athletes (4). In response to this, knee joint stabilisers have been developed, ranging from virtually immobilising devices to flexible high-tech systems.

In ball sports and sport activities involving direct body contact, the incidence of knee injuries has increased rapidly. Because ligamentous knee lesions were often diagnosed, industrial promotion has been focused on leisure activities. The increasing number of knee injuries

*Key words*: Proprioception training, postural stability, functional joint stability, reflex, prevention, rehabilitation, sensorimotor control.

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with degenerative disease has inspired biomechanical researchers to seek an understanding of the inherent factor that stabilises the joint complex (5).

Two different approaches in the research of an optimal joint stabilisation are reflected in literature. To prevent ligamentous disruption following injury or surgery, controversy exists about the efficacy of functional bracing and the application of functional rehabilitational braces. Epidemiological as well as experimental studies emphasize that precise fitting of an orthosis is one of the most important parameters to ensure a protective effect. Only slight variations to the optimal positioning might lead to high external loads to the ligaments of the joint complex.

Recently, a significant contribution to joint function via active mechanisms has been described in the literature. Gollhofer et al. (6) presented data indicating that the musculature encompassing the knee joint system can be effectively trained. The adaptions presented in their experiment reflect improved sensorimotor abilities and enhanced control of the knee joint system.

The purpose of the present study was to evaluate short and long term effects of a proprioception training on the knee function. Selected parameters of knee joint stability, postural stabilisation, and force production were measured comparatively before and after a 4-week training intervention. The proprioception training executed by the subjects consisted of coordination exercises affecting the ability to stabilise the upright stance on wobbly or uneven surfaces. These postural exercises, well known in rehabilitation of ankle and knee joint injuries, were expected to have a significant impact on the functional properties of the knee joint complex.

## MATERIALS AND METHODS

18 subjects (12 women and 6 men), comprising an age structure of 19-50 years, participated in this study. Their state of physical activity ranged from the elder recreational athlete to the younger sports student participating in low level performance. The proprioception training consisted of different balancing tasks on wobbly or uneven surfaces. The training was performed two times a week for one hour. The devices used for the training, such as soft matt gyroscope or tilt board were not used for the testing of the sensorimotor abilities. Before and after the 4-week proprioception training, functional stability of the knee joint was determined.

Active postural stabilisation was tested, in order to assess the intermuscular coordination at the lower extremity. Isometric maximum force tests were performed to determine the maximum voluntary force of the leg extensors.

Two simulations of injury mechanisms were performed to diagnose the functional stability of the knee joint complex. In order to estimate the active joint stabilisation, sudden joint displacements were applied, while the extend of the mechanical displacement and the correspondent neuromuscular activities were registered simultaneously.

The activation of the knee joint-embracing musculature (mm vastus medialis, vastus lateralis, semitendinosus and biceps femoris) was recorded by superficial electromyography (EMG). The angular displacements at the knee joint were determined with the help of an electronic two-axis goniometer and a torsiometer (Penny&Giles®).

The statistical processing covered the calculation of the characteristic descriptive values. Differences in means were tested on significance by paired t-tests on 5% level after normal distribution was examined.

### *Postural stabilisation*

The postural stability at the lower extremity was tested on a swinging platform (Posturomed®) under 2 conditions:

1) Determination of the raw displacement during a period of 40 seconds standing bare footed on the device. Here, the signals of the accelerometers were integrated twice. Thus, the covered distance of the stance platform during the stabilisation task could be determined. Deviations from the origin were determined for both degrees of freedom separately (medial-lateral and anterior-posterior). In order to receive information about the activation of the musculature, iEMGs in periods of 0-40 seconds were analysed.

2) Analysis of the ability to regain postural stability after medio-lateral perturbation during an 8-second period standing in a ski boot on the device. After perturbation, acceleration and EMG signals were recorded during a period of 10 seconds. The period between 0.2-8.2 seconds after perturbation was used for the data analysis. Also, damping of the platform was determined during this period.

The EMGs of the muscles mentioned above were recorded continuously during the measurements, as well as flexion, valgus-varus, and torsion of the knee joint. Accelerations in anterior-posterior and medial-lateral direction of the stance platform of the Posturomed® were registered using accelerometers (Kistler®, Switzerland).

### *Maximum isometric contraction*

A maximum voluntary isometric leg extension test at the leg press was performed. The execution of the measurements at the leg press corresponded to the standards of isometric maximum force measurements described in literature. A commercial device was used,

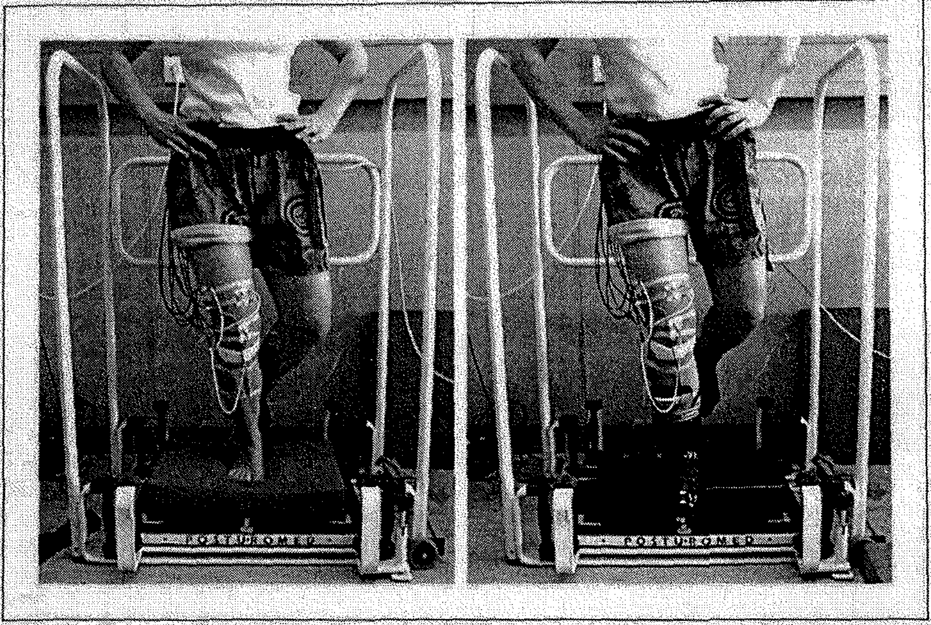

*Fig. 1 - Subject on swinging platform (Posturomed®) in one leg stance bare footed or with ski boot. Determination of displacement (left) and reaction on perturbation (right).*

with a three-dimensional operating force measurement platform (Kistler®) mounted.

From the isometric strength curve, the maximal amplitude and the maximum gradient were determined. Additionally, the force and corresponding iEMG values 30, 50 and 100ms after initial onset of force were determined.

### *Simulation of injury mechanisms on a tilt-platform*

A tilt-platform was used for the simulation of a typical injury mechanism to the knee joint. The release of the platform induced an inward rotation of the femur with an additional valgus movement at the knee joint. In order to enhance the amplitudes of the motion at the knee joint and to adapt the movement to the typical conditions of alpine skiing, the subjects were standing in ski boots fixed on the platform.

The subjects were instructed to stand as relaxed as possible on the tilt-platform (EMG - on-line check), which could be unlocked with an electromagnetic shutter system. Following platform release, a defined passive momentum was induced at the knee joint.

The movement of the platform was limited to 15° inward rotation in the frontal plane and 5° forward rotation in the sagittal plane. Thereby, the subjects knee was forced by gravity into a valgus movement in combination with a inward rotation of the femur on the tibia. Thus, defined joint movements could be applied unexpectedly, which came close to injury movement patterns to the knee joint. The start of the mechanical simulation could be registered accurately with the help of electrical switching signals (triggers).

The mechanical effects of the injury simulations were documented by the registration of maximum angle amplitudes, as well as by the maximum angular speed of torsion and valgus-varus movement in the knee joint. The reflex induced muscular activities were registered up to 180ms after releasing the platform.

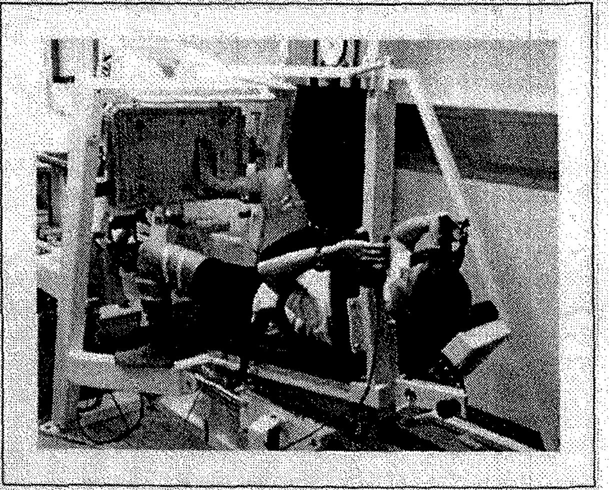

*Fig. 2 - Subject in the leg press for maximum voluntary isometric contraction.*

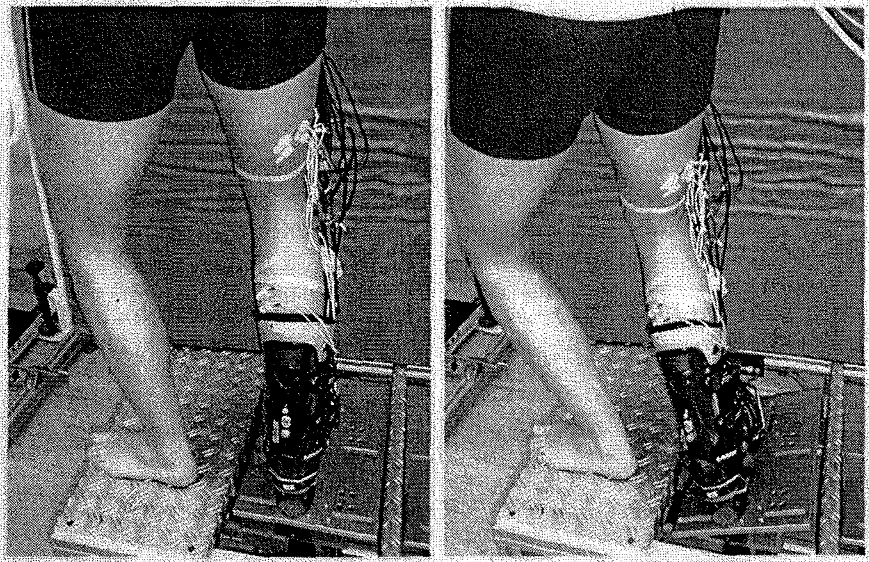

*Fig. 3 - Simulation of injury mechanism on the tilt-platform.*

### *Simulation of injury mechanisms by anterior tibial displacement*

The mechanisms of an anterior cruciate ligament disruption could be simulated in a testing situation. With a new device, it was possible to measure the stability of the knee joint with the subjects standing upright. The tibial displacement in relation to the femur could be measured under axial load of the leg.

In order to push the tibia in anterior direction, a weight was attached to the shank via a rope guided by a pulley. The force initiated to pull the tibia anteriorly was documented with a force transducer (Kistler®). The subjects were instructed to keep a knee angle of 30° flexion, which was registered with a goniometer (Penny&Giles®), as constant as possible. Thus, axial rotation of the tibia and rotation-

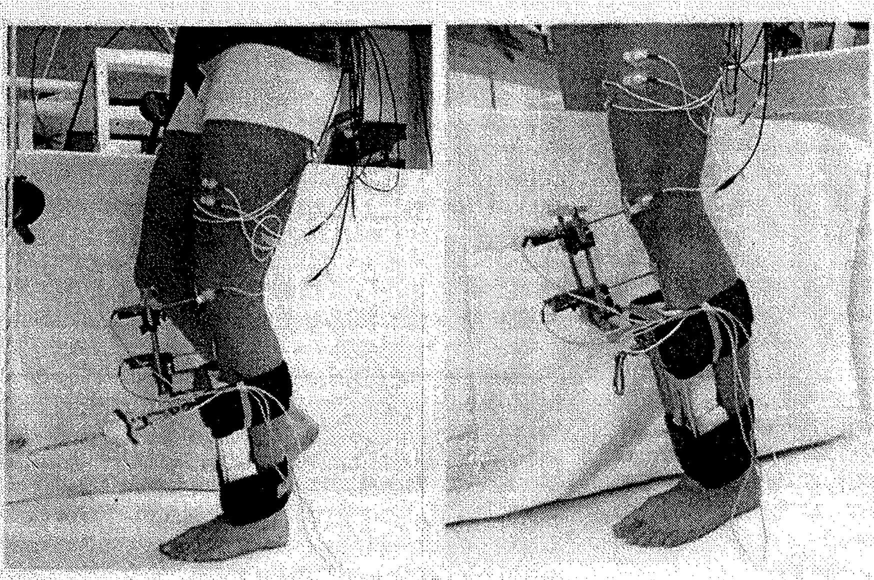

*Fig. 4 - Simulation of injury mechanism by anterior tibial displacement.*

caused influences on the measured data were minimized. Both legs were loaded equally. During the first120ms after the initial onset of force, the reflex-activation of the knee-stabilising muscles on the stimulus was measured by EMG.

## RESULTS

### *Postural stabilisation*

Significant improvements in postural stability were evident, documented by decreasing movement of the platform. Additionally, significant reduction of the torsion movement of the knee joint during the bare footed 40s-test could be detected. Regarding muscular stabilisation, an increase of the iEMG related to the movement of the platform and also related to the torsion of the knee joint occurred (Fig. 5).
In a second test, the balance was perturbed by a defined deflection of the swinging platform. The subjects had to counteract the oscillation to regain postural stability. This test was executed with the subjects standing in a ski boot.
Figure 6 shows the pre-post comparison of the damping values. After the training, the subjects could adjust a deflection from the resting position faster, and the mechanical damping increased significantly. The improved damping is accompanied by a pronounced activity of m. semitendinosus, as can be seen from the activation characteristic of the musculature.

### *Maximum isometric contraction*

The subjects could markedly increase their explosive force. Although, no change in maximum isometric strength could be detected. Muscle force output was increased especially during the first 100ms (Fig. 7). Increase in force came along with an increase in iEMG of the knee joint stabilising musculature at the same time.

### *Simulation of injury mechanisms on a tilt-platform*

In this injury simulation, a fast external tibial rotation in combination with a strong valgus movement was induced at the knee joint. After the training, a reduction of the torsion movement of the knee joint could be seen during the early reflex phase. This reduction of the torsion movement at the knee joint was accompanied by an increase of the activity of m. semitendinosus. Simultaneously, a slight decrease of m. biceps femoris activity was found (Fig. 8).

### *Simulation of injury mechanisms by dynamic tibial displacement*

The functional stability of the knee joint was represented by the stiffness of the joint system. Stiffness was calculated as a quotient of the initiated impulse and the resulting tibial displacement. Higher stiffness is equivalent to better stability of the knee joint during the test situation. Reflex induced activities of the knee stabilising muscles were recorded during the first 120ms after the onset of the pulling force. The iEMG was considered relatively to the activity 120ms prior to the onset of force.
Based on Figure 9, it can be deduced that the training increases joint stiffness. Simultaneously, the activity

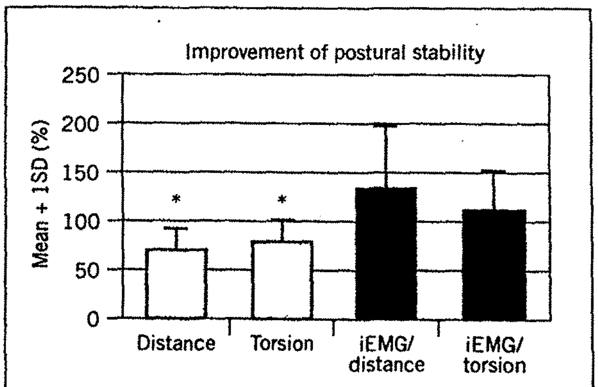

*Fig. 5 - Improvements of the subjects during the 40s-test represented by the movement of the platform (distance) and torsion of the knee joint. IEMG of all thigh muscles in comparison to the movement of the platform and to the torsion of the knee joint (pre-training = 100%; p<0,05).*
*Asterisks indicate significant differences in means pre-training compared to post-training (p<0.05).*

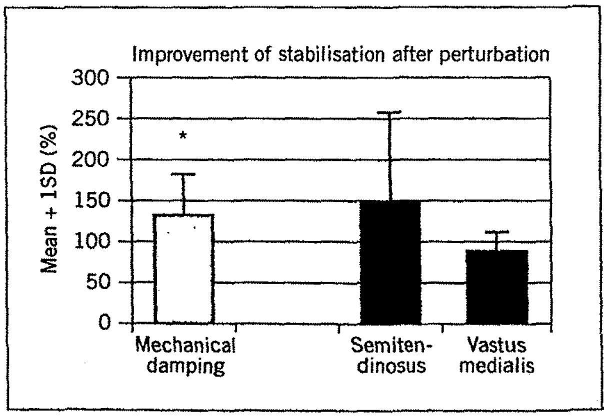

*Fig. 6 - Training induced modifications of the mechanical and muscular activation after medial-lateral deflection of the platform. The muscular damping is described by the quotient of iEMG 100-300ms after deflection and iEMG 1000-1200ms after deflection. (pre = 100%; p<0,05).*
*Asterisk indicates significant differences in means pre-training compared to post-training (p<0.05).*

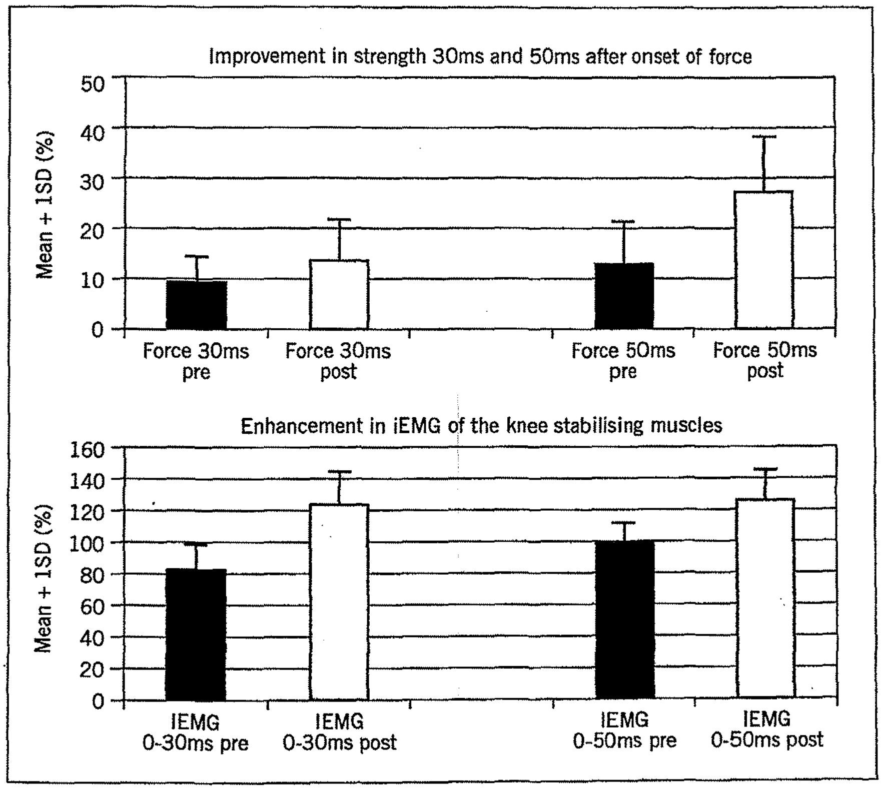

*Fig. 7 - Modifications of the force values 0-30ms and 0-50ms in percent of the maximum force (100%) and corresponding muscular activities of knee stabilising muscles.*

of the rear thigh muscles was increased. The activity of the hamstrings was increased up to 150% of the initial value before training.

## DISCUSSION

Functional stability of the knee joint and coordination of the lower extremity were measured in 4 different experimental set-ups to gain insight into the effects of a 4-week proprioception training. Postural stability measurement and maximum voluntary isometric contraction testing in a leg extension were performed to estimate movement coordination. Mechanical joint displacement and reflex contributions were measured in injury mechanism simulations in order to determine functional joint stability.

The results indicate an improvement of the sensorimotor characteristics of the knee joint, which can be attributed to the specific training. The modification of the central nervous control of the knee joint stabilising musculature caused an improvement of postural stability and explosive force production including the corresponding muscle activities. During sudden external application of forces and moments at the knee, functional stability of the joint was enhanced concerning both, the mechanical and the neurophysiological, parameters.

After the proprioception training, postural stability was markedly increased. Additionally, torsion movement at the knee joint was reduced. These findings point to the fact that, besides postural stability, also functional stability of the knee joint could be enhanced (7). The subject's reactions to external forces were more effective after training, because the movement of the platform was damped down faster.

Training within the area of the fast force development could increase muscle strength of the subjects. This increase was accompanied by just a slight change of the maximum isometric strength. Therefore, the improvement of muscle strength is not to be attributed presumably to an enlargement of the muscle cross sectional area, but to a better neuromuscular control (8).

The increase in fast force development was evident in the first 50ms. Before training, 13.5% of the achieved maximum force was produced within the first 50ms, while after training, already 26.8% of maximum force could be realised in the same time period.

The ability to stabilise the knee joint against rotations could be shown with the injury simulation on a tilt

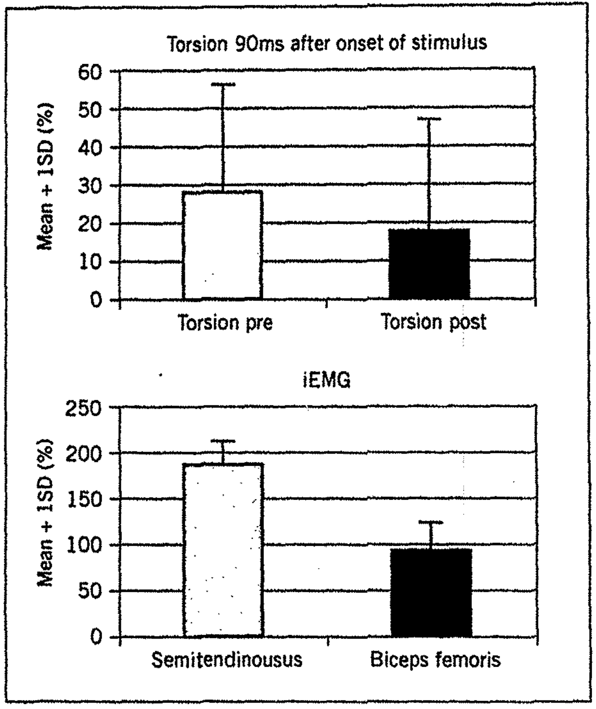

*Fig. 8 - Torsion 90ms after onset of stimulus in % of the maximum torsion, which is achieved during the test condition, and corresponding muscle activity (iEMG) of m. semitendinosus and m. biceps femoris (pre = 100%).*

platform. This simulation of injury mechanisms induced an inward rotation of the femur on the fixed tibia. The torsion movement of the knee joint was clearly reduced after the proprioception training. This reduction can be attributed to an improved sensorimotor control of the musculature (9).

After the proprioception training, the reflex response of the m. semitendinosus to the simulation was clearly enhanced, while the reflex response of the m. biceps femoris was slightly reduced. M. semitendinosus can counteract an inward rotation of the femur, while the m. biceps femoris would support this rotation due to its anatomical fixation. Thus, improvements of the intermuscular coordination can be documented as adaptations to the training, which may unfold an injury-preventive effect.

A stabilising effect of the proprioception training for the knee joint could be documented also in the simulation of injury mechanisms with an anterior displacement of the tibia. The stiffness was clearly increased after training. Again, this gain of mechanical stability can be attributed to improved sensorimotor control of the knee stabilising muscles (10).

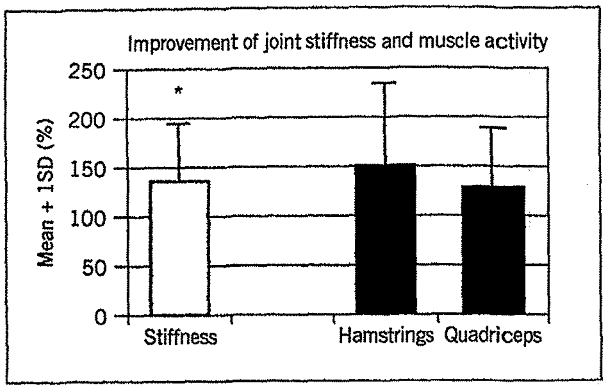

*Fig. 9 - Stiffness of the knee joint and muscle activities (iEMG) of the rear (hamstrings) and the front thigh musculature (quadriceps) in the first 120ms after initial onset of force (pre = 100%; p<0,05). Stiffness was calculated as a quotient of the initiated impulse and the resulting tibial displacement.*
*Asterisk indicates significant differences in means pre-training compared to post-training (p<0.05).*

The reflex activity of the knee-bending musculature was clearly increased in this testing condition after the proprioception training. The rear thigh muscles functionally constitute a synergistic unit with the anterior cruciate ligament, which can limit an anterior tibial displacement (11, 12).

The total activity of the knee joint stabilising musculature further plays an important role in joint stiffness. Increased muscular coactivation can produce enhanced axial compression forces in the joint, leading to higher friction between the joint surfaces. Thereby, an additional stability gain can be produced (13, 14). Thus, the observed, slight increase in activity of the front thigh musculature can also contribute to increased joint stiffness. Within the reflex measurements, situation-adequate activation of the knee joint muscles could be detected. These neuromuscular modifications led to a clear increase in mechanical stability of the knee joint (15).

The subjects were able to improve the coordination and knee joint stability by a 4-week, regularly executed proprioception training, which contained above all proprioceptive items. It increased postural stability and improved the ability to compensate unexpected perturbations of the lower extremity. The proprioception training can be recommended without limitations as a helpful instrument for injury prevention and for movement coordination.

To what extent the coordinative improvements can affect performance on a competitive level can only be assumed at present. Whether, for instance, athletes in competitive sports can improve efficiency by such a proprioception training remains unclear. Therefore, another substantial research requirement still exists in this area.

## REFERENCES

1. Kendall E.R., Schwartz J.H., Jessel T.M.
Principles of neural science. Appleton & Lange, Conneticut, 1991, pp. 270-732.
2. Schmidt R.A., Lee T.D.
Motor control and learning: A behavioural emphasis. Human Kinetics, Champaign IL., 1999, pp. 93-130.
3. Lephart S.M., Fu F.H.
Proprioception and neuromuscular control in joint stability.
Human Kinetics, Champaign IL., 2000, pp. 1-115.
4. Steele J.R.
ACL injuries in sport: Are they preventable? ISBS'99, XVII International Symposium on Biomechanics in Sports, Perth, proceedings, 1999, pp. 261-274.
5. Gollhofer A., Lohrer H., Alt W.
Propriozeption - grundlegende Überlegungen zur Sensomotorischen Steuerung. Orthopädieschuhtechnik - Sonderheft Propriozeption, C. Maurer Verlag, Geislingen, 2000, pp. 10-14.
6. Gollhofer A., Alt W., Lohrer H.
Prevention of excessive forces with braces and orthotics. In: Nigg B.M., MacIntosh B.R., Mester J. (Eds.), Biomechanics and biology of movement, 2000, pp. 331-349.
7. Schlumberger A., Schmidtbleicher D.
Zur Erfassung und Trainierbarkeit propriozeptiver Fähigkeiten.
Sportverletz. Sportschaden, 12: XXI-XXIV, 1998.
8. Haekkinen K., Allen M., Komi P.V.
Changes in isometric force- and relaxation-time, electromyographic and muscle fibre characteristics of human skeletal muscle during strength training anddetraining. Acta Physiol. Scand., 125: 573-585, 1985.
9. Lohrer H., Bruhn S., Gruber M., Alt W., Gollhofer A.
Sensomotorische Trainierbarkeit von knie- und sprunggelenkstabilisierenden Muskeln.
In: Jerosch J. (Ed.), Aktuelle Aspekte zur Sensomotorik und Propriozeption in Forschung, Klinik und Praxis. Tagungsband des Kongresses Sensomotorik (08.-09.09.2000 Neuss), 215-228, 2000.
10. Bruhn S., Gollhofer A., Lohrer H.
Funktionelle Stabilität am Kniegelenk - Verletzungs- und trainingsbedingte Unterschiede.
Sportorthop. Sporttraumatol., 3: 145-154, 2000.
11. Solomonow M., Baratta R., Zhou B.H., Shoji H., Bose W., Beck C., D'ambrosia R.
The synergistic action of the anterior cruciate ligament and thigh muscles in maintaining joint stability.
Am. J. Sports Med., 15: 207-213, 1987.
12. Johansson H., Sjölander P., Sojka P.
A sensory role for the cruciate ligaments.
Clin. Orthop., 5: 161-178, 1991.
13. Baratta R., Solomonow M., Zhou B.H., Letson D., Chuingard R., D'ambrosia R.
Muscular coactivation. The role of the antagonist musculature in maintaining knee stability.
Am. J. Sports Med., 2: 113-122, 1988.
14. Solomonow M., Krogsgaard M.
Proprioception control of knee stability.
Scand. J. Med. Sci. Sports, 11: 64-80, 2001.
15. Gruber M., Bruhn S., Gollhofer A.
Training induced adaptions of functional stability of the knee joint.
Proceedings of 5th annual congress of the European College of Sport Science Jyväskylä, Finland, 296, 2000.