

# Neuromuscular Response to Cyclic Loading of the Anterior Cruciate Ligament

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**Background:** Cyclic load applied to various joints during occupational and sports activities is epidemiologically linked to higher risk of neuromuscular disorder development.

**Hypothesis:** Passive cyclic loading of the knee will develop laxity and creep in the anterior cruciate ligament, and these may elicit a neuromuscular disorder in the quadriceps and hamstrings. Women may be more susceptible to the disorder.

**Study Design:** Controlled laboratory study.

**Methods:** Male and female groups were subjected to 10 minutes of passive cyclic loading (0.1 Hz) of the knee at a mild load (150-200 N) and at 35° and 90° flexion. Anterior tibial displacement and electromyogram from the quadriceps and hamstrings were monitored during cyclic loading. Maximal voluntary contraction of knee extension and flexion was assessed before and after cyclic loading. The effect of gender and angle on maximal voluntary contraction and quadriceps/hamstrings electromyogram was tested by a 2-way analysis of variance. Differences between the preload and postload data were tested by a paired *t* test.

**Results:** At a knee angle of 90°, after cyclic loading, a decrease in maximal voluntary contraction during extension was present in men and women, with an associated decrease in quadriceps electromyogram activity. At 35°, a decrease in maximal voluntary contraction in extension was noted in women and men. Electromyogram spasms were present in the quadriceps and hamstrings during the 10-minute cyclic loading in 51.7% of subjects. Analysis of variance demonstrated that ligament creep was significantly greater in women than in men at both knee angles.

**Conclusions:** Even a mild cyclic loading of the anterior cruciate ligament, for a relatively short period, can elicit substantial creep, laxity, and a neuromuscular disorder. The disorder is composed of spasms and attenuated muscular function that may together create a condition that exposes the knee to injury. Women seem to be more susceptible than men.

**Clinical Relevance:** Cyclic actions performed at high frequencies and high-load magnitudes may lead to the occurrence of increased knee laxity and changes in neuromuscular function that, together with fatigue and changes in proprioception, may increase the risk of injury.

**Keywords:** knee; anterior cruciate ligament (ACL); cyclic; electromyogram (EMG); disorder

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The development of knee instability is of great interest in occupational and sports medicine. Instability is related to an increased risk of knee and ligament injuries, which is one of the main reasons for disability associated with temporary or prolonged interruption of daily and/or sports activities.

The physiologic basis of knee injuries is closely related to the intrinsic characteristics of ligaments and to the response of the associated muscles to external loads.<sup>33,38</sup> To confirm epidemiologic data,<sup>13,28,32</sup> several experimental

studies performed on animal preparations and humans<sup>5,6,8,20,31,35,36,39,40</sup> have shown that static and cyclic loads elicit creep in the ligaments of various joints, followed by substantial changes in the reflexive activation of associated muscles. Such a neuromuscular disorder was shown to consist of a decrease in the EMG activity over time. Furthermore, the appearance of random and unpredictable EMG spasms also represents tissue damage and neuromuscular impairment.<sup>9,23,25,42,43</sup> Physiologically, ligament creep is associated with laxity and with desensitization of the reflex arcs initiated by the mechanoreceptors present in the ligament,<sup>9,16</sup> thereby decreasing the reflexive muscle activity and exposing the joint to possible further instability and injury. As a consequence, the mechanical stability can be impaired because of laxity of viscoelastic tissues and their attenuated ability to signal muscles of important changes in joint stability.

Knee laxity has been demonstrated and was more pronounced in women than in men because of hormonal and anatomical factors that make ligaments more susceptible to damage.<sup>2,7,15,22,30,41</sup> The increased risk of developing knee injuries reported in women might also be related to an increased quadriceps activation not counterbalanced by antagonist coactivation; this activity may increase anterior tibial shear forces, placing the ACL at higher risk for knee injury.<sup>5,41</sup>

It has also been reported that ACL tension and, therefore, function<sup>11,29</sup> change as a function of knee angle. Furthermore, quadriceps and hamstrings coactivation was shown to protect the knee from ACL injury.<sup>1,3,11,24,37,38</sup> Therefore, ACL function and synergistic muscular activity protect the knee at variable levels as a function of the knee angle.

A recent study<sup>5</sup> showed that 10 minutes of static load applied to the knee elicits creep of the ACL, and this is accompanied by the presence of EMG spasms and an increased quadriceps activation (hyperexcitability) after loading. All these features were dependent on the knee angle (more evident at knee angle of 35°) and, being more pronounced in women, supported previous findings.<sup>2,7,41</sup> Similar findings were found for lumbar ligaments subjected to static loads.<sup>36</sup> The neuromuscular response to cyclic loading of the knee is not known. Cyclic loading of the knee occurs routinely in normal daily activities: walking, running, bicycling, jumping, and so forth. Having an insight on this subject might help in preventing or limiting the occurrence of ACL injuries.

The objective of this study was to investigate the influence of a passive cyclic load applied to the knee joint on the development of ACL creep and muscular function in healthy men and women. We hypothesized that creep developing in the ACL during a short period of passive cyclic load would result in significant changes in the function of the thigh muscles, which may lead to increased risk of injury. We also expected women to be more susceptible to the development of such transient neuromuscular disorder. Because of potential risk, only mild loads were used. The passive load paradigm was chosen to eliminate the effect of fatigue from compounding the data.



Figure 1. Experimental setup.

## MATERIALS AND METHODS

### Subjects

Fourteen healthy subjects (7 men, 7 women; age:  $26.8 \pm 5.4$  years; body mass: men,  $73.7 \pm 8.2$  kg; women,  $59.7 \pm 7.6$  kg; height: men,  $178 \pm 8.3$  cm; women,  $168 \pm 8.4$  cm) participated in the study after signing an informed consent form approved by the institutional review board.

### Experimental Setup

The subjects were comfortably seated on a custom-designed chair with the knee angle fixed at either 35° or 90° (see "Protocol"). The subject was stabilized by a strap placed across the proximal thigh and another one across the pelvis, as shown in Figure 1.

The skin over the muscles was cleaned with rubbing alcohol prep pads, and 2 pairs of 1-cm-diameter silver/silver chloride electrodes (30-mm interelectrode distance) were applied. The electrodes were applied longitudinally over the muscle bellies of the quadriceps (rectus femoris) and hamstrings (biceps femoris and semitendinosus) between the motor point and the distal tendon. Each electrode pair constituted the input to a custom-made differential amplifier of 110-dB common-mode rejection ratio, a gain capability of up to 200 000, and a band pass filter of 5 to 500 Hz. The EMG was also monitored continuously on an oscilloscope. After the knee was in place, the ankle was strapped to a padded polypropylene cuff, connected via a rod to a load cell for maximal voluntary contraction (MVC) measurements. A padded strap was applied around the posterior proximal tibia, just below the knee, and was connected via a steel cable and pulleys to the vertical actuator of a Bionix Material Testing System (MTS Inc, Minneapolis, Minn) that was used to apply a cyclic load to the proximal tibia with a computer-controlled loading system operated in a load control mode. The MTS actuator was also used to indirectly measure the ACL creep via the

anterior tibial displacement. The line of action of the cable was perpendicular to the tibia at any of the 2 positions. Any compliance in the system (cables, pads, soft tissue, etc) was removed by a preload (see "Protocol").

The 2 EMG signals, the flexion-extension force, as well as the anterior tibial displacement and cyclic load of the MTS actuator were acquired by a 12-bit A/D board at a rate of 1000 samples per second and stored in the computer for further analysis.

## Protocol

After the subject was seated with the knee angle fixed at 90°, the maximal voluntary force was assessed during isometric knee extension and flexion (MVC). Three 5-second trials were performed with 3 minutes of rest in between. During the MVC trials, each subject had to exceed the mark set by the previous trial as fixed on an oscilloscope to ensure true MVC.<sup>34</sup> To prevent the use of the arms during the MVC tests, subjects were asked to fold their arms across the chest. The peak force values obtained during maximum extension (MVC<sub>ext</sub>) and flexion (MVC<sub>flex</sub>) were used for subsequent analysis.

After the MVC assessment, a 20-N preload was applied to the tibia via the MTS actuator connected to the proximal tibia through a padded strap attached to a cable guided over a pulley system. This preload was applied to remove any compliance in the system as well as to provide standard baseline across the subjects. Then, an anterior cyclic load (at 0.1 Hz) was applied to the tibia. The peak load was set to 200 N for the men and 150 N for the women (approximately 20% of body weight). Reduced loads were applied to women because of reduced body mass and stature. Therefore, the load applied ranged between 20 and 200 N for the men and between 20 and 150 N for the women. An internal safety control was applied via software to the MTS actuator so that if the load exceeded the target value (200 N for men, 150 N for women), the machine would automatically stop to avoid an accidental overloading. The EMG and ACL displacement were recorded continuously during the cyclic loading. Each subject was exposed to 3 cycles before the 10-minute loading period started to test the system (EMG, compliance, noise, etc).

After the 10-minute cyclic load, the subjects performed a second set of 3 MVCs in extension and flexion using the same procedure as above. At the end of the experimental session, subjects were asked to walk normally and to report any sensation felt concerning the knee stability. A 30-minute rest in a supine position was then given to allow recovery from any symptoms reported.

The same experimental procedure was repeated in all subjects after 2 weeks with the knee angle fixed at 35°.

## Data Analysis

The EMG signal was analyzed via a mean absolute value (MAV) algorithm with a time window width of 200 milliseconds. The algorithm consisted of an absolute value function applied to the digitally recorded signals followed by averaging 100 points before and 100 points after the

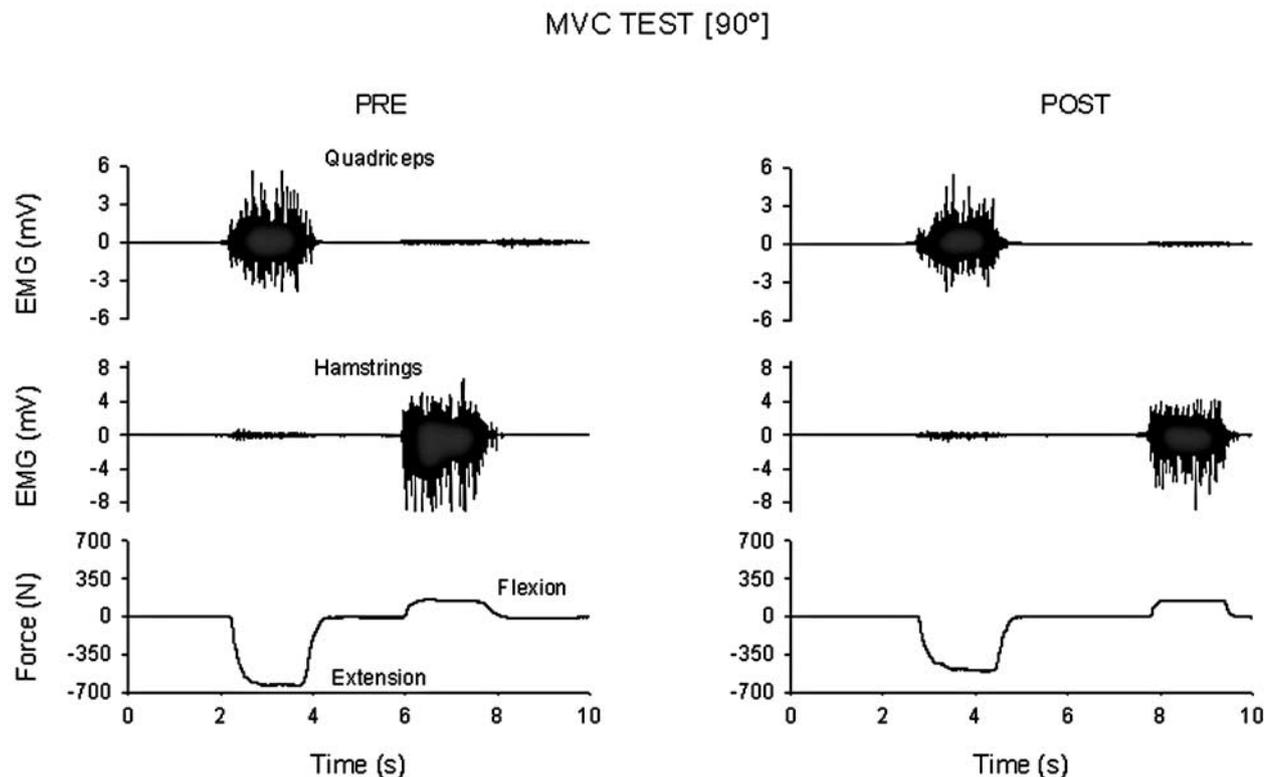
point over which the window was centered. The peak force and MAV values obtained during flexion and extension in the preload MVC tests (MVC<sub>ext</sub> and MVC<sub>flex</sub>, hamstrings MAV Ago-Flex and quadriceps MAV Ago-Ext) were used as representatives of agonist and antagonist EMG activity values for each muscle and peak flexion and extension forces. Peak force and peak MAV obtained in the postload MVC tests were normalized to the maximum value obtained from the same muscle during the preload MVC tests while acting as agonist. The ACL creep was measured as the difference between the peak initial anterior displacement (obtained during the first 0.1-Hz cycle) and the peak displacement value obtained at the end of the 10-minute cycle. Data are reported as mean values and correspondent SEs.

An analysis of variance (ANOVA) was used to test the effect of angle and gender on the postload flexion and extension force (MVC<sub>flex</sub> and MVC<sub>ext</sub>, respectively), quadriceps agonist and antagonist EMG activity (MAV Ago-Ext and MAV Antago-Flex, respectively), hamstrings agonist and antagonist EMG activity (MAV Ago-Flex and MAV Antago-Ext, respectively), and ACL creep. Differences between the preload and postload parameters were assessed by a paired *t* test implemented with Bonferroni correction when appropriate. Statistical significance was set at  $P < .05$ .

## RESULTS

Typical MVC and associated EMG recordings obtained before (Figure 2, left) and after (Figure 2, right) the 10-minute cyclic load was applied to the tibia are shown in Figure 2. Typical examples of the cyclic load, ACL displacement, and EMG activity recorded from the quadriceps and hamstring muscles during the 10-minute cyclic load at different knee angles are shown in Figure 3 (A-E). In the top 2 traces, quadriceps and hamstrings EMGs are shown, and the bottom traces represent the ACL displacement and the cyclic load, respectively. As is shown in the EMG recordings, the EMG activity was characterized by the presence of random, unpredictable spasms (Figures 3 A-D). In Figure 3E, recordings without spasms are shown for comparison. The spasms were observed in 8 (57.1%) of the 14 subjects (3 men, 5 women). EMG spasms of the hamstrings were mainly observed during cyclic loading at 35°, whereas spasms in the quadriceps EMG were equally distributed between the 35° and 90° conditions.

During the 10-minute cyclic load, anterior tibial displacement was observed in all subjects in both experimental conditions (see Figures 3 A-E). The mean displacement obtained after the 10 minutes of cyclic loading at 35° was  $9.13 \pm 0.4$  mm in the women (mean creep, 18.98%) and  $7.07 \pm 0.4$  mm in the men (mean creep, 16.3%). In the 90° experiment, the mean ACL displacement was  $8.68 \pm 0.4$  mm in the women (mean creep, 20.6%) and  $7.23 \pm 0.5$  mm in the men (mean creep, 14.85%). The ANOVA revealed a significant effect of gender on the creep developed ( $P = .001$ ), whereas no effect of angle ( $P = .39$ ) as well as interaction effects (gender and angle,  $P = .11$ ) were found.



**Figure 2.** Typical maximal voluntary contraction (MVC) and EMG recording from quadriceps and hamstrings before and after the 10-minute cyclic load in 1 subject. In the top 2 traces, the EMG activity of quadriceps and hamstrings is shown. The bottom trace represents the extension and flexion MVC before and after the 10-minute cycle.

In Table 1, the mean and SEs of the normalized data from all subjects are shown. As already mentioned in the previous section, because the trials at 35° and 90° were performed in different sessions, the data from each subject were normalized within session, and the statistical analysis refers to the changes from before to after ACL creep. Hence, the  $MVC_{ext}$  and  $MVC_{flex}$  before creep as well as the corresponding agonist quadriceps and hamstrings EMG activity before ACL creep (MAV Ago-Ext and MAV Ago-Flex, respectively) are set as normalizing factors, with a mean value of 100 and an SE of 0.00. All of the following results are therefore represented as a percentage of variation of all considered parameters with respect to the pre-load condition.

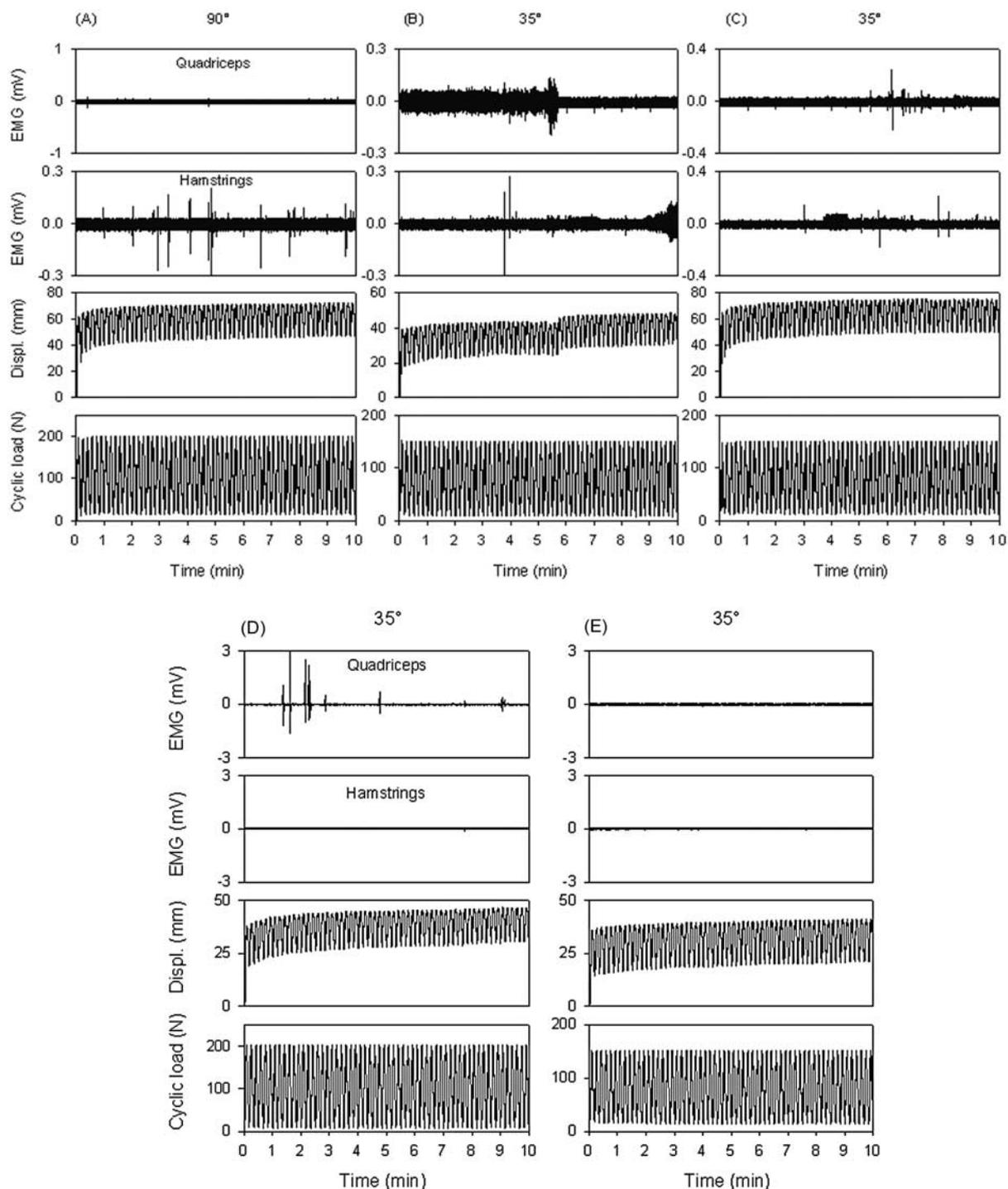
During the experiment performed with the knee angle fixed at 90°, the mean  $MVC_{ext}$  significantly decreased after the 10 minutes of cyclic load by 10.72% ( $P = .0009$ ), with an 11.75% decrease observed in men and a 9.2% decrease in women. The force decrease was accompanied by a significant decrease ( $P = .01$ ) in EMG activity of agonist muscles (MAV Ago-Ext: 16.67% decrease in women, 11.5% decrease in men); a decrease in EMG activity of antagonist muscles (MAV Ant-Ext: 12.4% decrease in women, 21.6% decrease in men) was also obtained, but in this case this decrease was only a trend ( $P = .07$ ). No change in the  $MVC_{flex}$  and EMG agonist/antagonist activity was observed.

When the knee angle was maintained at 35°, a significant ( $P = .01$ )  $MVC_{ext}$  decrease of 24.86% was observed in women after the 10 minutes of passive cyclic load; force decrease was paralleled by a tendency toward a decrease in the EMG activity of agonist and antagonist muscles (MAV Ago-Ext decrease: 5.45%; MAV Antago-Ext decrease: 8.16%), although it was not significant ( $P = .16$ ). Men also showed a trend, although not significant, toward  $MVC_{ext}$  decrease (mean decrease: 6.92%,  $P = .48$ ) after the 10 minutes of cyclic load, whereas the EMG activity of both agonist and antagonist muscles during  $MVC_{ext}$  was not significantly modified after the 10 minutes of passive cyclic load. The  $MVC_{flex}$  was not significantly changed in both men and women after the 10 minutes of cyclic load.

No significant changes were observed in the EMG activity of either agonist or antagonist muscles during  $MVC_{flex}$  as a consequence of the 10 minutes of cyclic load.

The ANOVA results (Table 2) show a significant effect of angle on the EMG activity of antagonist muscles during knee flexion ( $P = .0004$ ). This effect consisted of a significantly higher MAV Antago-Flex during  $MVC_{flex}$  at 35° compared to the 90° condition. No effect of gender, no effect of angle, and no interaction effect were observed on all the other considered parameters.

At the end of the 10-minute cyclic test, 9 (64.3%) subjects (5 men, 4 women) reported a subjective sensation of light knee instability/laxity that was accompanied by ham-



**Figure 3.** Five typical recordings from 5 different subjects at 90° and 35°. In the top 2 traces, the EMG recordings from quadriceps and hamstrings during the 10-minute cycle are shown. The 2 bottom traces represent the anterior tibial displacement and the cyclic load, respectively. Note the presence of EMG spasms in both the quadriceps and hamstrings (A-D). An example with no reflex EMG activity is also reported (E). Displ, displacement.

string stiffness in 2 subjects (1 man, 1 woman); these features disappeared after the 30-minute rest after the test. Further elaboration by the subjects revealed that light knee instability consisted of the sensation that the joint

may have buckled during weightbearing in the stance phase of the tested leg. One subject (female) reported a sensation of instability, stiffness, and soreness in the hamstrings during the action of descending stairs, felt the day

TABLE 1  
Summary of the Mean (SE) Normalized Data of All Subjects<sup>a</sup>

	Preload								Postload							
	Men				Women				Men				Women			
	35°		90°		35°		90°		35°		90°		35°		90°	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
MAV																
Ago-Ext <sup>b</sup>	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00	100.86	18.73	88.53	10.13	95.45	7.61	83.33	6.97
MAV Antago-Ext	27.54	9.26	18.94	4.69	22.42	6.82	15.40	3.73	15.32	3.74	14.83	2.68	20.59	6.78	13.49	3.15
MVC <sub>ext</sub> <sup>b</sup>	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00	93.07	8.93	88.25	3.67	75.13	6.98	90.80	2.76
MAV Ago-Flex <sup>b</sup>	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00	93.19	6.43	90.85	9.99	94.33	15.51	98.21	6.68
MAV Antago-Flex	28.38	10.81	6.39	0.65	21.70	6.26	9.94	2.77	20.22	3.70	6.43	1.08	19.04	5.77	8.83	2.28
MVC <sub>flex</sub> <sup>b</sup>	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00	92.30	5.47	101.02	6.79	99.21	3.04	94.82	2.41

<sup>a</sup>MAV, mean absolute value; Ago-Ext, agonist-extension; Antago-Ext, antagonist-extension; MVC, maximal voluntary contraction; Ago-Flex, agonist-flexion; Antago-Flex, antagonist-flexion.

<sup>b</sup>For the preload data, these items are normalizing factors and hence have a mean of 100 and an SD of 0.00.

TABLE 2  
Analysis of Variance Results<sup>a</sup>

Parameter	Effect of Angle	Effect of Gender
MAV Ago-Ext	.28	.63
MAV Antago-Ext	.16	.77
MVC <sub>ext</sub>	.39	.22
MAV Ago-Flex	.94	.71
MAV Antago-Flex	.0004 <sup>b</sup>	.89
MVC <sub>flex</sub>	.65	.94
ACL displacement	.76	.001 <sup>b</sup>

<sup>a</sup>Data are *P* values. MAV, mean absolute value; Ago-Ext, agonist-extension; Antago-Ext, antagonist-extension; MVC, maximal voluntary contraction; Ago-Flex, agonist-flexion; Antago-Flex, antagonist-flexion.

<sup>b</sup>Values are significant.

after the experimental session; full recovery in this subject was obtained in 2 days.

DISCUSSION

The major findings of this study consisted of the development of spasms and creep in the ACL during 10 minutes of mild cyclic loading and the attenuated function of the thigh muscles after cyclic loading. Furthermore, women seemed more susceptible to develop creep, spasms, and decrease in muscle function as compared to men. The disorder was sensitive to knee angle, regardless of the gender.

Before discussing the results in perspective, it should be pointed out that the load applied to the knee in this experiment was relatively mild, and this was chosen to prevent the subjects from exposure to injury, thereby observing

ethical considerations. It is common for the knee to sustain loads that are equal to or exceed body weight. For example, in the single-stance phase of going up or down stairs, a daily function, the full weight is transmitted through the knee. This load is in the order of 600 to 800 N for an average person. The loads used in this study were 150 N and 200 N in female and male subjects, respectively: a mild load of 20% to 25% body weight. Therefore, it was expected that the applied load would provide just sufficient insight to determine if cyclic loading elicited changes in neuromuscular functions and to thereby verify the hypothesis. Indeed, statistically significant results as well as some trends were present to confirm the hypothesis. It is reasonable to anticipate that significance across all the variables would be present if the load could be safely increased 2- or 3-fold.

Furthermore, it should be pointed out that the anterior displacement of the tibia was measured. The displacement and the creep calculations, therefore, included the stiffness offered by various tissues, including the ACL, collateral ligament, passive muscle/tendons, and so forth. Hence, one can assert that general knee laxity was directly measured. That measurement, however, indirectly represents the axial laxity of the ACL, as it is the major restraint of the knee in the angles and direction of loading used in this experiment.

The ACL anterior displacement and creep observed were greater in women than in men, without showing differences in the 2 experimental conditions (35° and 90°). This finding is in accordance with what was previously observed<sup>5</sup>; in fact, as already stated in the introduction, women show a greater laxity of ligaments because of hormonal, anatomical, and biomechanical factors.<sup>2,7,15,22,30,41</sup>

The mean ACL displacement observed after 10 minutes of cyclic load (7-9 mm) was lower than that observed in a previous work (12-15 mm, on average) that employed static loads of identical magnitudes.<sup>5</sup> This difference might be

explained on the basis of the different loading conditions used in the 2 studies. In the previous study, a static load was applied to elicit ACL creep, thus resulting in the inability of viscoelastic tissues to partially recover during the 10-minute static tension. Conversely, the cyclic protocol used in this study might have allowed a certain degree of recovery between cycles, thus resulting in a lower cumulative ACL creep.

During the 10 minutes of cyclic load, random spasms were observed within the EMG signal. This pattern was observed in 8 of 14 subjects (51.7%), in both muscles, being more pronounced in the women. According to a number of studies,<sup>9,14,21,23,25,42,43</sup> the presence of spasms within the EMG is a sign of tissue microdamage and represents non-voluntary response to an excessive stress induced by cyclic or static stretch to the viscoelastic tissues. At a knee angle of 35°, EMG spasms were mostly observed in the hamstrings, in accordance with what was previously observed.<sup>5</sup> It is known that knee angles near 35° induce maximal strain in the ACL, with additional increase in strain as the quadriceps contracts.<sup>11,29</sup> The spasms observed in the 35° experiment would take place to reduce the stress in the ACL, as hamstrings contraction at this angle has a direct effect in reducing anterior tibial displacement. It should be noted that the presence of EMG spasms observed in this study was marginally supported by subjective signs. Overall, 64% of subjects referred to a very light or no sensation of knee laxity or instability immediately after the 10 minutes of cyclic load. In 2 subjects (1 man, 1 woman), a sensation of knee instability was felt the day after the experiment during the action of climbing stairs, accompanied by soreness and stiffness in the hamstrings. Both cases were related to the experiment performed while the knee angle was 35°. This condition (knee angle at 35°) is known to increase the risk for ACL injury,<sup>10,11,29</sup> and this would explain the subjective symptoms reported; nevertheless, 2 of 14 subjects represent a very low percentage and cannot be considered representative of a phenomenon. To confirm what was suggested above, this finding might be another sign indicating that the loads used were mild, and therefore were the responses obtained.

The results provided by the ANOVA revealed a significant effect of angle on the EMG activity of quadriceps muscles while acting as antagonist during  $MVC_{flex}$ . A higher quadriceps activation was observed in the 35° experiment compared to the 90° experiment. The higher quadriceps EMG activity was observed in men and women either before or after the 10 minutes of cyclic load, without showing significant changes from the precycle to the postcycle condition. This result was not completely surprising and supported what is reported in the literature concerning the concept that extremely flexed and extended positions favor an increased laxity of the knee joint,<sup>10</sup> which is promoted by an increased agonist (quadriceps) activity not compensated by the activity of the antagonist (hamstrings).

An important finding obtained in this study consisted of a significant decrease in the  $MVC_{ext}$  after the 10 minutes of cyclic load that was observed in both men and women at 90° and 35°, even though in the 35° condition the  $MVC_{ext}$

decrease was a trend only in men. Force decrease was associated with a decrease in agonist (quadriceps) EMG activity and by a tendency toward a decrease in antagonist (hamstrings) activation.

Generally speaking, a decrease in force after a certain kind of effort can be attributed to muscle fatigue, which is excluded in the experimental condition applied here (passive cyclic load). In an attempt to provide a reasonable explanation supporting this unexpected result, the relationship between peripheral and central factors in voluntary activation pattern has to be taken into account. Maximal voluntary force is governed by the activation of the alpha-motoneurons originated by the central nervous system, but central neural drive is continuously adjusted in accordance with the peripheral information coming from mechanoreceptors in the ligaments<sup>12,26,27,44</sup> and other afferents.<sup>19</sup> A decrease in MVC and quadriceps EMG activity was observed after 20-minute vibrations were applied to the infrapatellar tendon of the uninjured side in ACL patients.<sup>17,18</sup> The authors concluded that loss of feedback from mechanoreceptors in the ACL could be the underlying mechanism of persistent quadriceps weakness often observed in ACL patients. Reduction in maximal voluntary activation as an effect of tonic vibration has been demonstrated in different conditions,<sup>4,19</sup> and this finding has been explained on the basis of a gamma loop dysfunction originated by an attenuation of Ia afferent function mediated by muscle spindle. Because force decrease was associated with a decrease in EMG activity of agonist muscles in our study, and this correlation was in accordance with previous studies,<sup>17-19</sup> it would be tempting to explain these results on the same basis. Most important, it has been demonstrated<sup>16,40</sup> that ligamentous creep promoted in both cyclic<sup>6,40</sup> and static<sup>36</sup> conditions is associated with a desensitization of the reflex arcs initiated by the mechanoreceptors present in the ligaments, resulting in an impairment of the reflexive neuromuscular response. According to the experimental design adopted in the present study, it is reasonable to argue that the loss of voluntary activation might have been promoted by a loss of sensitivity of the mechanoreceptors occurring as a consequence of the cyclic load and the resulting laxity of the ACL.

From the results obtained in this study, it may be concluded that 10 minutes of mild anterior cyclic load applied to the knee resulted in mechanical and neuromuscular changes consisting of creep development in the ACL and spasms within the EMG signal, as well as decreasing extension force after loading; ACL creep was more pronounced in women.

The load applied to the knee was passive; that is, it did not require voluntary muscular activity to perform cycling, running, stair climbing, and so forth, as in real-life sports or occupational activities. The reasoning for selecting passive loading was to exclude the effect of additional loading of the knee by the musculature as well as muscle fatigue. In reality, however, the ACL will be subjected to additional loads as a result of quadriceps activity in the range of 35° to 90°, for example. These additional loads will further increase the displacement and creep. Furthermore, as active exercise progresses over time, fatigue also sets in

the muscles and decreases their function. Overall, in real-life conditions, the results we presented here will be further compounded by additional displacement/creep from forces coming from the muscles, followed by less support or protection of the joint as the muscles fatigue. Another important aspect associated with ligamentous creep is related to decrease in proprioception and ligamentous-muscular protective reflexes. As the laxity in the ACL increases with increase in creep, the mechanoreceptors within will not operate at the same length/force threshold. Such laxity will decrease the mechanoreceptors discharge into the spinal cord and, consequently, their proprioceptive and reflexive responses. It is clear that additional degradation in knee stability will be associated with deficient proprioception and reflexive activity, increasing the risk of injury.

The results of our study suggest that a cyclic load applied to the knee in a clinical situation might lead to increased knee laxity and neuromuscular dysfunction and, thus, might increase the risk of ACL or other knee injury.

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