Progressive versus rapid rate of contraction during 7 wk of isometric resistance training

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ABSTRACT

MAFFIULETTI, N. A., and A. MARTIN. Progressive versus rapid rate of contraction during 7 wk of isometric resistance training. *Med. Sci. Sports Exerc.*, Vol. 33, No. 7, 2001, pp. 1220–1227. **Purpose:** The aim of this study was to compare the effects of isometric training performed with progressive versus rapid rate of contraction on the knee extensor neuromuscular properties over a 7-wk period. **Methods:** Sixteen healthy male subjects trained quadriceps femoris muscle in a leg extension machine three times a week during 7 wk. The training sessions consisted of six sets of six maximal isometric contractions. A first group trained by performing progressive contractions lasting 4 s, whereas a second group performed contractions with a rapid rate of contraction (i.e., ballistic contractions) lasting about 1 s. **Results:** Both groups significantly increased the isometric and isokinetic voluntary torque, and the respective absolute or relative gains were comparable. Isometric training performed with progressive rate of contraction affected the evoked action potential (M wave) of the vastus lateralis muscle and not the related twitch properties. On the other hand, the isometric training completed with ballistic contractions significantly modified the twitch contractile properties of the knee extensors and not the associated M waves of both vastus medialis and vastus lateralis. **Conclusion:** Knee extensors adapted specifically their neuromuscular properties to the type of rate of contraction performed during 7-wk isometric resistance training. Progressive isometric contractions produced modifications of the nervous system at peripheral level (i.e., muscle membrane electrical activity), whereas ballistic isometric contractions affected the knee extensor contractile muscle properties (i.e., excitation-contraction coupling). **Key Words:** TORQUE/ANGLE RELATIONSHIP, TORQUE/ANGULAR VELOCITY RELATIONSHIP, SURFACE EMG, M WAVE, TWITCH CONTRACTILE PROPERTIES

It has been demonstrated that a maximal voluntary isometric contraction (MVC) can be increased by a period of isometric resistance training lasting from 5 to 12 wk (20,22). The physiological adaptations after isometric training remain nevertheless a subject of discussion. Indeed, many studies have attempted to obtain additional informations about the possible sites (central vs peripheral) to which the strength gains could be attributed. Some authors have reported an increased electromyographic (EMG) activity of the trained muscles especially at the training position, attributed to an increased neural drive to muscle (4,19,28). Recent investigations have failed to show modifications of the surface EMG, therefore rejecting the hypothesis of an increased neural drive to trained muscle (9,10,16,25,30). For example, Carolan and Cafarelli (10) have shown that increases in knee extensor strength resulting from isometric training depended on reduced antagonist co-contraction. MVC increases observed after isometric strength training have also been attributed to adaptations occurring at peripheral sites. Muscular hypertrophy (16) and contractile muscular adaptations (25) have been reported for the knee extensor muscles. For instance, twitch contractile adaptations are the result of changes in muscle properties and not the result of alterations in a central recruitment pattern. The question of whether isometric resistance training could affect these properties has yet to be clearly checked. Indeed, many investigators reported no modifications in twitch contractile characteristics (12,13,19,22,29), whereas others showed that isometric resistance training has an effect on twitch contraction time (2,3), maximal twitch force, (15,25) and maximal rate of twitch tension development (25). Differing training protocols may account for some of the discrepancies.

Indeed, all previous studies have applied isometric training protocols composed of contractions lasting 3–10 s, and very few have focused on force-time development. Thépaut-Mathieu et al. (28) reported that peak force was progressively reached in 1 or 2 s during training. Rich and Cafarelli (25) and Behm and Sale (5) imposed a rapid rate of force development, although it is unclear how the contraction was arranged in the other protocols. Moreover, only one attempt was made to investigate the effects of brief isometric contractions performed with a rapid force-time development (i.e., attempted ballistic contractions) (5). These authors showed that ballistic isometric training produced the same effects on the dorsiflexor neuromuscular properties than isokinetic concentric training performed at high angular velocity (5.23 rad$\cdot$s^{-1}—300°$\cdot$s^{-1}). More recently, Rich and Cafarelli (25) have shown that 8 wk of isometric contractions lasting 3–5 s and performed with maximal rate of force development produced no alterations of the control properties of the nervous system despite sizeable changes in the contractile properties of quadriceps femoris muscle. Based on these results and on Behm and Sale's suggestions (5), it seems that the type of muscle action appears to be of lesser importance, being the rate of contraction the principal

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TABLE 1. Subjects' descriptive physical characteristics by group (values are mean and SD).

	Trained Subjects					
	PROG (N = 8)		BALL (N = 8)		Control Group (N = 5)	
	Mean	SD	Mean	SD	Mean	SD
Age (yr)	24.5	4.4	21.6	2.0	28.4**	3.7
Mass (kg)	73.8	4.0	71.6	4.2	76.6	4.4
Height (cm)	181.0	4.4	177.3	3.8	178.4	5.6

** Significantly older than BALL subjects at $P < 0.01$.

stimuli for the training response. Therefore, it could be of interest to study, for the same form of resistance training (i.e., isometric), the differential effects of the rate of contraction (maximal vs progressive) on the central nervous system and the peripheral contractile mechanism.

Thus, the aim of the present study was to compare the effects of ballistic versus progressive isometric training performed at 100% MVC, over a 7-wk period, on knee extensor nervous and muscular properties. We analyzed the myoelectric and mechanical responses obtained under maximal voluntary and evoked conditions to distinguish neural adaptations from contractile changes.

METHODS

Experimental group and training procedure. Approval for the project was obtained from the University of Burgundy Committee on Human Research. Twenty-one healthy male subjects, all free from previous knee injury, volunteered to participate and signed an informed consent form. None of them had previously engaged in systematic strength training or high-level sport practice. Subjects were randomly assigned to two experimental groups (PROG and BALL, $N = 8$) and one control group (C, $N = 5$). The descriptive physical characteristics of the three groups of subjects are presented in Table 1. The subjects of the control group did not train and were tested before and after a 7-wk period to assess the reliability of the observations. PROG and BALL subjects trained individually in a leg extension machine (Multi-Form, La Roque D'Anthéron, France) equipped with a commercially available dynamometer (Allegro, Sallanches, France) three times a week for 7 wk. At the beginning of all training sessions, 12 submaximal isometric muscle contractions (from 30% to 80% of the last MVC) preceded an MVC measure. Training sessions consisted of six sets of six two-sided isometric contractions at a knee angle of 65° of flexion (0° = knee fully extended), with an 18-s rest between repetitions and 3 min between sets. PROG subjects trained by developing a maximal voluntary isometric contraction lasting 4 s, with an imposed and standardized progressive force-time development (25% of the MVC every second). BALL subjects were encouraged to climb as fast as possible to the MVC (i.e., maximal rate of force development), with the order to stop rapidly the contraction when the maximal value was reached (i.e., maximal rate of relaxation). The isometric contraction thus completed lasted about 1 s. Visual feedback of the force level was provided for all the subjects during all the training sessions and verified by the examiner. All measurements were performed on the dominant leg before and after the 7-wk period using the same procedure. The tests were completed over two different sessions, separated by a 3-d interval.

Isometric and isokinetic voluntary strength testing. Each of the 21 subjects who took part in this study reported to the laboratory for the first testing session. Isometric and isokinetic strength measures were carried out on the same Biodex dynamometer (Biodex Corporation, Shirley, NY). To minimize hip and thigh motion during the contractions, straps were applied across the chest, pelvis, mid-thigh, and lower leg. A strap also secured the leg to the Biodex lever arm, and the alignment between the center of rotation of the dynamometer shaft and the axis of the knee joint was checked at the beginning of each trial. The arms were positioned across the chest with each hand clasping the opposite shoulder. Torques were gravity-corrected at each joint angle, where the gravity effect was greatest (27). Subjects warmed-up performing five submaximal concentric actions at the three experimental angular velocity (i.e., $-60°$, 60°, and $240° \cdot s^{-1}$) and three submaximal isometric contractions at the training position (i.e., 65° knee flexion). Isometric measurements were performed at three different knee angles (55°, 65°, and 75°) to realize torque/angle relationship. These efforts lasted 5 s, and the rate of contraction was freely chosen by every subject. Isokinetic measurements involved two maximum concentric or eccentric contractions of the knee extensors (range of motion 90°), performed at three preset constant angular velocities ($-60°$, 60°, $240° \cdot s^{-1}$). Constant angular torque at 65° knee flexion was computed directly by the Biodex software and included in the torque/angular velocity relationship. The velocity throughout each repetition was analyzed, and it was also verified that, at the higher angular velocity (i.e., $240° \cdot s^{-1}$), constant angular torque was developed during the constant velocity period. Isometric and isokinetic trials were randomly presented with a 3-min rest between successive repetitions to eliminate the effects of fatigue. In each case, only the best performance was included in the analysis.

Electrically evoked twitch contractile properties. In the second testing session electrical stimulations were given using a high-voltage stimulator (model DS7, Digitimer Stimulator, Hertfordshire, England) with the subject seated on the isokinetic dynamometer and the knee joint fixed at 65° of flexion. The femoral nerve was stimulated using a cathode ball electrode (0.5-cm diameter) pressed in the femoral triangle while the muscle was at rest. The anode was a rectangular electrode (Medicompex SA, Ecublens, Switzerland), 50 cm^2 (10 cm × 5 cm), located in the gluteal fold opposite the cathode. The amperage (20–100 mA) of a rectangular pulse (1 ms in duration) was progressively increased in order to obtain a plateau in the twitch torque and in the amplitude of the EMG signals (M wave, see Surface Electromyography below). Once this was achieved, five stimuli were delivered over a 20-s period with a 5-s rest between each. The twitch torque obtained from the Biodex dynamometer was digitised on-line (sampling frequency 1000 Hz) and stored with commercially available software (Tida, Heka Elektronik, Lambrecht/Pfalz, Germany). We measured from the average signal of the five consecutive twitch traces: a) peak twitch force (PT), i.e., the highest value of twitch torque production; b) twitch contraction time (CT), i.e., the time to twitch maximal force, calculated from the origin of the mechanical signal; c) maximal rate of twitch tension development (RD), i.e., the first derivative of the torque signal; d) maximal rate of twitch relaxation (RR), i.e., the first derivative of the decline of torque; and e) half relaxation time (HRT), i.e., the time of half of the decline in twitch maximal force.

Surface electromyography. The EMG signal from the vastus medialis (VM) and vastus lateralis (VL) muscles was recorded bipolarly by silver chloride surface electrodes during strength testing and transcutaneous electrical stimulation. The recording electrodes were fixed lengthwise over the middle of the muscle belly (14) with an interelectrode (center-to-center) distance of 20 mm. The reference electrode was attached to the wrist of the opposite arm. Low impedance at the skin-electrode surface was obtained ($Z < 2k\Omega$) by abrading the skin with emery paper and cleaning with alcohol. Myoelectrical signals were amplified with a bandwidth frequency ranging from 1.5 Hz and 2 kHz and simultaneously digitised on-line (sampling frequency 1000 Hz) and stored on a PC. For voluntary strength testing, the root mean square (RMS) myoelectric activity of both VM and VL was calculated every 0.02 s over the period of interest. During isometric actions, the EMG signals were analyzed over a 1-s period after the torque had reached a plateau. During isokinetic actions, signals were analyzed between 55° and 75° of the complete movement to exclude nonisokinetic activity. The average EMG RMS values thus obtained were normalized to the RMS of the respective M wave of the session to account for differences in electrical impedance and electrode placement. The RMS/angle and RMS/angular velocity relationships of both VL and VM muscles were thus determined before and after training. We measured from the average signal of five electrically evoked action potentials (M wave) the peak-to-peak amplitude, duration, and the RMS of the whole potential, for both VM and VL muscles.

Statistical analyses. Ordinary statistical methods including means and their SD or SE were calculated for each parameter. The differences between pre- and post-training results were tested for all parameters by a Student's *t*-test for paired observations. A one-way ANOVA was used to compare the differences between the PROG, BALL, and C groups, before and after the 7-wk period. When significant treatment effects occurred, LSD *post hoc* analysis were used to test significant differences among means. In each case, the level of significance was established at $P \leq 0.05$.

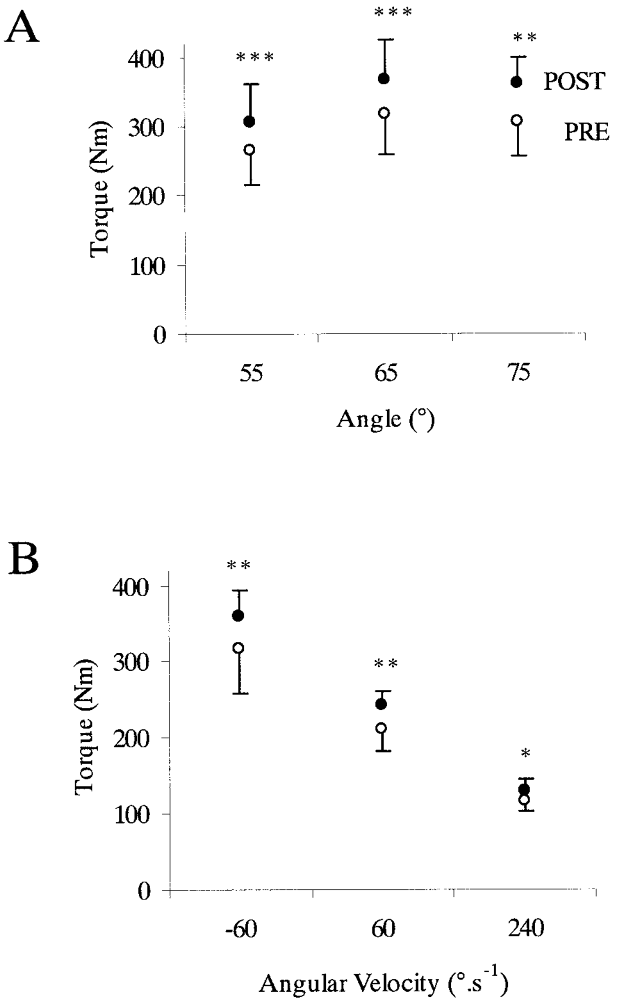

FIGURE 1—Knee extensors torque/angle (A) and torque/angular velocity (B) relationships obtained before (*open circles*) and after (*filled circles*) 7-wk resistance training performed with progressive isometric contractions. Values are means ± SD; *, **, and * indicate that posttraining torque values were significantly higher than pretraining values at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively (Student's *t*-test for paired observations).**

RESULTS

Torque/angle, torque/angular velocity relationships and related EMG activity. Figures 1 and 2 show the effects of 7 wk of isometric resistance training performed with progressive (Fig. 1) and ballistic (Fig. 2) contractions on knee extensor isometric (A, upper panels) and isokinetic (B, lower panels) voluntary torque. No significant difference was observed at baseline between the PROG, BALL, or C group in torque values. The two forms of isometric training resulted in a significant increase of the MVC at the training position (i.e., 65° knee flexion). The relative gains were, respectively, 15.7% for PROG and 27.4% for BALL ($P < 0.001$). Significant and comparable torque increases were also observed at 55° ($P < 0.001$) and 75° ($P < 0.01$) knee angles for both groups. No significant

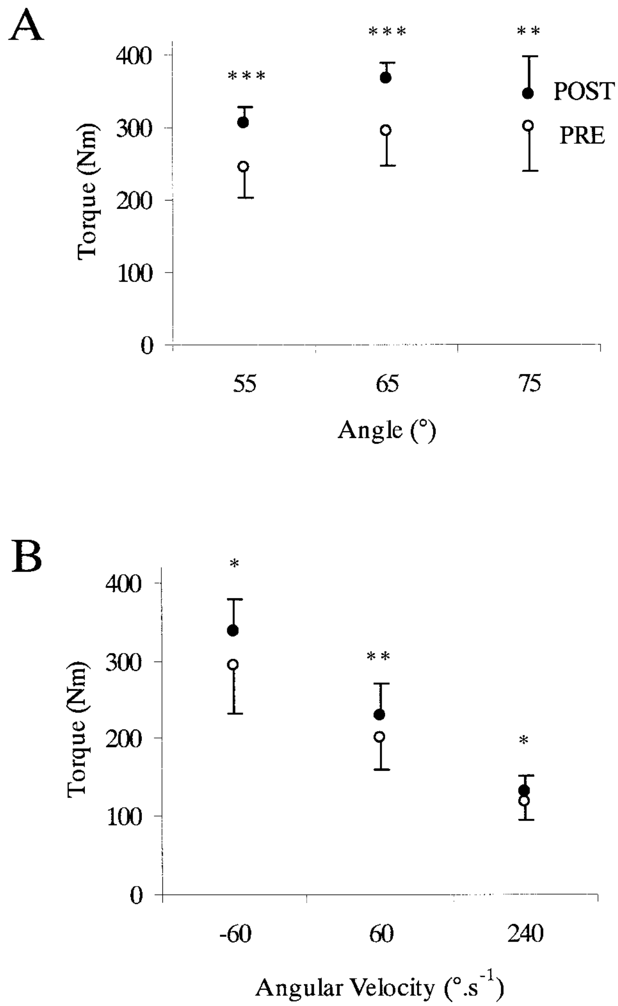

FIGURE 2—Knee extensors torque/angle (A) and torque/angular velocity (B) relationships obtained before (*open circles*) and after (*filled circles*) 7-wk resistance training performed with ballistic isometric contractions. Values are means ± SD; *, **, and * indicate that posttraining torque values were significantly higher than pretraining values at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively (Student's *t*-test for paired observations).**

difference was observed between the two experimental groups when considering the absolute or the relative changes in isometric torques. The isokinetic torque significantly increased at the three angular velocities considered for both PROG and BALL subjects. Under eccentric conditions, torque increased by 15.6% for PROG ($P < 0.01$) and by 18.3% for BALL ($P < 0.05$). Significant and comparable torque increases were also observed at the slow ($P < 0.01$) and fast ($P < 0.05$) concentric angular velocities for both groups. No significant difference was observed between the two forms of isometric training in the absolute or the relative isokinetic torque changes. In the C group, isometric and isokinetic torque values were not significantly different after the 7-wk period (Table 2).

The surface electromyographic RMS activity of the VM and VL muscles was analyzed during torque measurements (see, Methods). To account for differences in electrical impedance and electrode placement, for each subject these RMS values were normalized to the RMS of the M wave of the session. No significant difference was observed before training between the PROG, BALL or C groups in the normalized RMS activity of both isometric and isokinetic contractions. Table 3 shows the relative changes in RMS/angle and RMS/angular velocity relationships calculated for the three groups of subjects and for the VM and VL muscles. The normalized RMS activity of the VL was significantly lower after the 7-wk resistance training in PROG subjects under isometric conditions at 55° knee flexion and at the two concentric velocities considered ($P < 0.05$). For the same group, no significant changes were observed on the VM muscle. When considering the BALL and C groups, no significant changes occurred after the 7-wk period on the VM and VL muscles during isometric and isokinetic torque assessment.

Vastus lateralis and vastus medialis M-wave characteristics. The peak-to-peak amplitude, duration, and RMS of the compound action potential (M wave) obtained by electrical stimulation of the femoral nerve before and after the 7-wk period are represented in Figure 3, for the three groups of subjects and for the VM (A, left panels) and VL (B, right panels) muscles. No significant difference was observed at baseline between the PROG, BALL, or C groups in M-wave characteristics. The vastus medialis M-wave characteristics were unchanged after the 7-wk period, whatever the group of subjects. Conversely, the amplitude, the duration and the RMS of the vastus lateralis M wave increased after progressive-type training, respectively, at $P = 0.055$, $P = 0.054$, and $P = 0.028$. No changes in vastus lateralis M-wave characteristics were observed in the BALL or C groups after the 7-wk period.

Knee extensor twitch contractile properties. Figure 4 shows the electrically evoked twitch contractile properties of the knee extensors before and after the 7-wk period for the three groups of subjects. No significant difference was observed at baseline between the PROG, BALL, or C groups. The subjects trained with progressive-type isometric contractions showed comparable twitch contractile properties before and after training. On the other hand, ballistic-type contractions during isometric training resulted in a significant increase in peak twitch torque ($P < 0.05$), contraction time ($P < 0.01$), and maximal rate of twitch relaxation ($P < 0.01$) and in a significant decrease of the half relaxation time ($P < 0.001$). In the C group, knee extensor twitch contractile properties were not significantly different after the 7-wk period.

DISCUSSION

The present study indicated that 7-wk isometric resistance training performed with two different rates of contraction (progressive vs rapid) significantly increased the knee extensor concentric, eccentric, or isometric voluntary torque. Although voluntary torque gains were comparable between progressive and ballistic training, the electrically evoked M waves and the associated twitch torque were differently affected by the two forms of training. Isometric training performed with progressive 4-s contractions modified the

TABLE 2. Knee extensor torque/angle and torque/angular velocity relationships for control group before and after the 7-wk period (values are mean (SD) in Nm).

	Torque/Angle			Torque/Angular Velocity		
	55°	65°	75°	$-60°\cdot s^{-1}$	$60°\cdot s^{-1}$	$240°\cdot s^{-1}$
Before	305.5 (90.1)	333.9 (91.4)	293.2 (82.73)	324.7 (59.8)	258.3 (58.3)	156.5 (28.4)
After	324.8 (77.9)	361.6 (93.9)	327.0 (77.5)	346.7 (50.8)	271.9 (57.9)	166.8 (34.5)

vastus lateralis M-wave characteristics with no influence on the resulting twitch. Isometric training completed with brief ballistic contractions affected knee extensor twitch contractile properties, whereas the associated M waves showed no changes.

Many investigators have focused on isometric resistance training performed with contractions lasting 3–10 s; however, the type of rate of contraction adopted in training protocols has not always been reported. Typically, no emphasis is put on a rapid rate of force development, and therefore a low- rather than high-velocity-specific training response is produced (5). In the present study, the voluntary torque gains were similar between subjects trained with progressive and ballistic isometric contractions performed at 100% MVC. We interpret these results as indicating that a rapid rate of contraction in isometric training exercise is not more efficient to produce greater torque increases as compared with a progressive rate of contraction and *vice versa*. Likewise, the duration of the contraction (4 s vs 1 s) seems not to play an essential role for the maximal torque development. Instead, the key training stimuli appear to be the maximal intensity of the isometric contraction (i.e., 100% MVC). As a matter of fact, the magnitude of the increase in knee extensor MVC observed in this study is similar to what others have found with comparable resistance overloads (10,16,18). An interesting and relevant result is that the two forms of isometric training (i.e., progressive and ballistic) led to a significant increase of the voluntary isometric torques but also of the voluntary torques developed under dynamic conditions (eccentric and concentric).

The underlying mechanisms of increase in muscle torque production in response to isometric training can result from changes which may occur at various sites along the pathway from the central nervous system through to the peripheral contractile mechanism. Increases of the EMG activity at the trained joint angle observed after isometric resistance training are usually attributed to an increased neural drive to muscle (4,19,28). However, lots of recent investigations have failed to show modifications of the vastus lateralis and vastus medialis EMG after an isometric training lasting 6–8 wk (10,16,25,30). In the present study, the EMG RMS activity at the training position (i.e., 65° knee flexion) was unchanged after the 7-wk period for all our groups of subjects and for both VM and VL muscles. The total electrical energy contained in surface EMG signal is proportional to the number of active motor units and their firing frequency (8). Because all motor units in a muscle are maximally activated during MVC (6,10,16,23), an increase in EMG would have to be secondary to an increase in motor units firing rate (i.e., the "rate coding"). However, Rich and Cafarelli (25) have recently furnished experimental evidence that the average firing rates of the vastus lateralis were not different after 8 wk of isometric resistance training. Furthermore, the motor unit firing behavior (21) during fast contraction basically may be the same as during slow contraction. We are therefore justified in assuming that isometric training performed with progressive or ballistic contractions has no apparent effect on the central neural drive of the vastus medialis and vastus lateralis muscles. However, because EMG recordings from vastus intermedius and rectus femoris were not made, increases in neural drive to these muscles cannot be ruled out based on the data presented here.

The EMG RMS activity was also monitored during isometric contractions other than at the training position and during dynamic contractions (eccentric and concentric). No changes were observed for the subjects trained with ballistic contractions or for the control group for both VM and VL muscles. On the other hand, the RMS of the VL significantly decreased at 55° knee flexion and under concentric conditions for the subjects trained with progressive rate of contraction. As an explanation for these surprising results, the RMS activity was normalized with respect to the RMS of the M wave, and consequently an increase of this latter would result in a decrease of the former. Indeed, the vastus lateralis M-wave characteristics were affected by the isometric training performed with progressive rate of force development. Peak-to-peak amplitude and duration

TABLE 3. Relative changes of vastus medialis (VM) and vastus lateralis (VL) EMG RMS activity during isometric and isokinetic actions from baseline to 7-wk later (values are mean (SD) in %); for the three groups of subjects RMS values were normalized to the RMS of the respective M wave.

	RMS/angle						RMS/angular velocity					
	55° VM	55° VL	65° VM	65° VL	75° VM	75° VL	$-60°\cdot s^{-1}$ VM	$-60°\cdot s^{-1}$ VL	$60°\cdot s^{-1}$ VM	$60°\cdot s^{-1}$ VL	$240°\cdot s^{-1}$ VM	$240°\cdot s^{-1}$ VL
PROG	−2.4 (40.9)	−23.1* (33.4)	5.2 (38.7)	−8.2 (32.2)	14.6 (57.6)	−8.9 (40.9)	6.0 (39.7)	−13.4 (24.6)	2.1 (52.1)	−26.6* (29.6)	6.5 (49.3)	−25.6* (16.0)
BALL	5.8 (40.0)	7.6 (48.3)	−1.0 (38.1)	4.3 (41.4)	−1.1 (39.4)	−0.2 (37.8)	−7.3 (24.2)	−2.4 (44.1)	−10.7 (25.6)	−8.2 (32.0)	−12.7 (35.8)	−9.8 (42.1)
CONTROL	11.3 (18.8)	7.4 (23.6)	2.9 (16.3)	−1.4 (25.6)	0.1 (15.9)	−5.9 (26.3)	6.6 (25.8)	4.8 (28.8)	8.9 (19.4)	−2.3 (26.3)	3.9 (22.2)	0.9 (16.5)

* Significant change at $P < 0.05$.

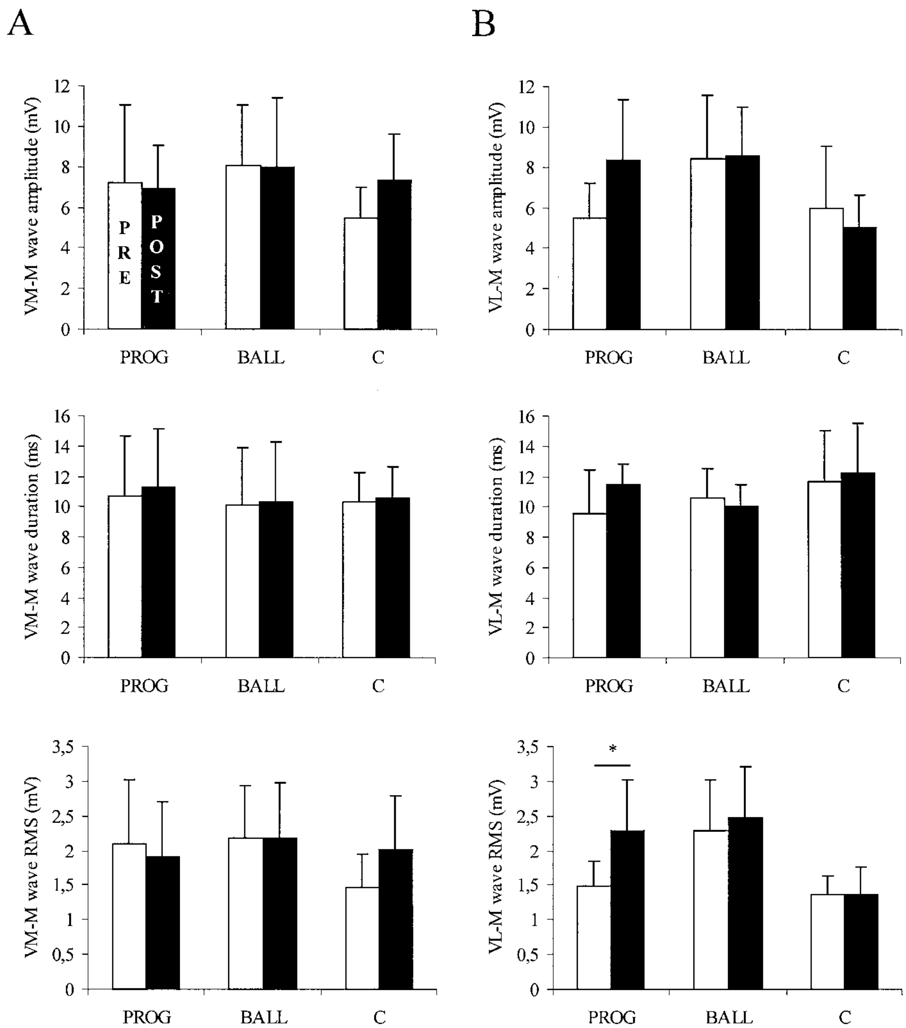

FIGURE 3—Vastus medialis (A) and vastus lateralis (B) M-wave amplitude (upper panels), M-wave duration (central panels), and M-wave RMS (lower panels) in the progressive (PROG), ballistic (BALL), and control groups (C), before (*white bars*) and after (*black bars*) the 7-wk period. Values are means ± SD; * indicates that posttraining values were significantly higher than pretraining values at $P < 0.05$ (Student's *t*-test for paired observations).

augmented, and consequently the RMS significantly increased after the 7-wk period, which in turn indicated that modification of the muscle membrane electrical activity occurred at peripheral level. As previously suggested, a slowed M wave seemed to be mediated by ionic processes (7,24). This result seems somewhat surprising because 1) no modifications in the resulting twitch time course were observed, and 2) the M wave of the vastus medialis showed no changes. Although the recording and interpretation of the surface EMG can sometimes be problematic, in the present study, we exercised considerable care to avoid detrimental effects. Moreover, the point of stimulation in the femoral triangle was marked on the skin so that it could be exactly repeated between experiments, and the results obtained on the control group clearly confirm the reliability of the measures.

Although a slowed M wave of the vastus lateralis was observed after isometric training performed with progressive contractions, the consequential twitch showed no changes. We expected, for example, an increase in the twitch contraction time, as reported by Colson et al. (11), but this was not the case. These authors observed a slowed M wave of the biceps brachii associated with a significant increase of the twitch time to peak, therefore explained by a slower conduction velocity along the muscle fibers. However, their isometric training was performed under stimulated conditions (i.e., electrostimulation) of the elbow flexor muscles and the intensity of the isometric contractions was submaximal (i.e., 60–70% of the MVC). Many other studies have failed to show modifications of the contractile properties of different muscles after isometric training performed with contraction lasting 3–5 s (12,13,19,22,29). However, no author has focused: (i) on the knee extensor muscular group, (ii) on standardized progressive isometric contractions, and (iii) on the ensemble of twitch contractile properties reported in the present investigation.

Under evoked conditions, the group of subjects trained with ballistic isometric contractions showed differential adaptations as compared with their progressive counterparts. Indeed, the surface compound action potentials of both VM and VL were unaltered although this form of training significantly affected the associated twitch contractile properties. Twitch contractile adaptations are the result of changes in muscle properties and not the result of psychological factors or alterations in a central recruitment pattern, because the contractile properties are electrically evoked. At our knowledge, only one study has reported the effects of isometric training performed with maximal rate of

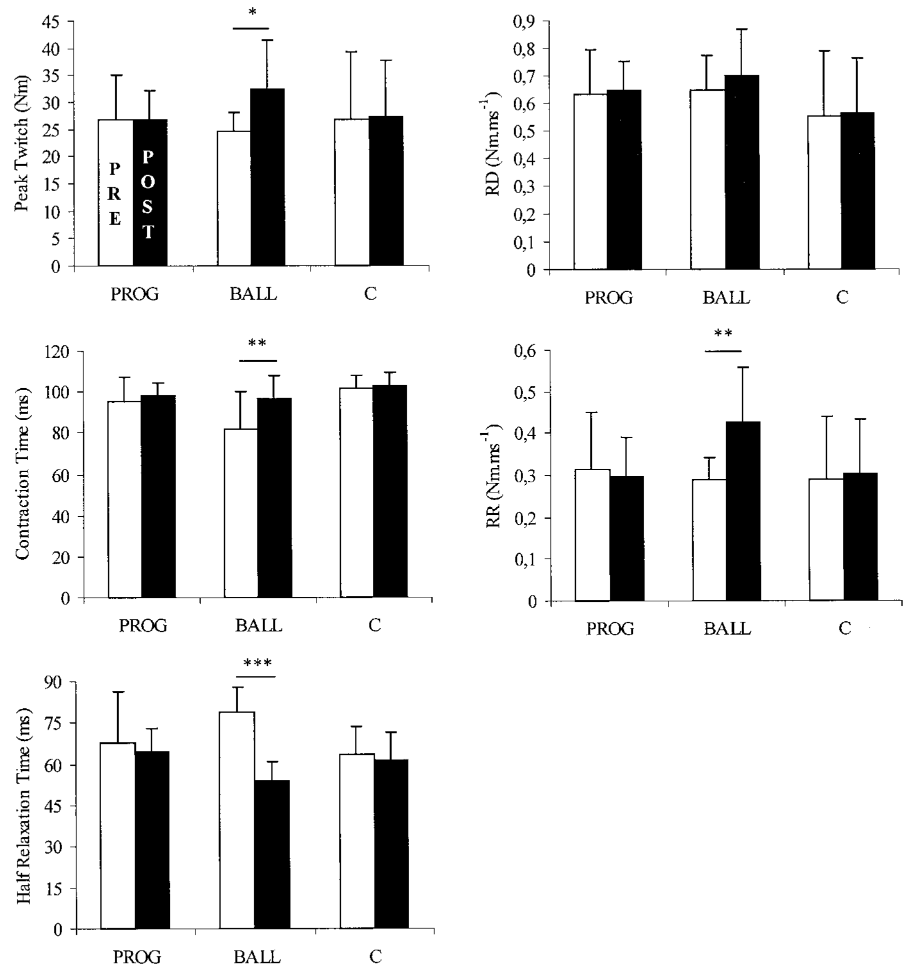

FIGURE 4—Knee extensors twitch contractile properties in the PROG, BALL, and C groups before (*white bars*) and after (*black bars*) the 7-wk period. Values are means ± SD; *, **, and * indicate that posttraining values were significantly different from pretraining values at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively (Student's *t*-test for paired observations); RD, maximal rate of twitch tension development; RR, maximal rate of twitch relaxation.**

contraction on the knee extensor twitch contractile properties (25). These authors have found significant increases in peak twitch torque (+17%) and maximal instantaneous rate of contraction (+20%) after 8-wk isometric resistance training. In the present study, the peak twitch significantly increased (+29.8%) after ballistic training, and these gains were superimposable to those obtained for the MVC (+27.4%). We were surprised to notice that the maximal rate of twitch tension was only slightly and not significantly modified (+4.2%). Indeed, one could expect a greater increase of this latter because the present protocol involved isometric contractions performed with maximal rate of force development. This result is in contrast with Rich and Cafarelli (25), even though their isometric contractions were maintained 3–5 s, whereas our ballistic efforts were suspended at the MVC value. Another intriguing result is represented by twitch contraction time. In fact, ballistic-type isometric training prolonged time to peak twitch as a result of a greater twitch amplitude, whereas other studies have shown the contrary (1,3). Other experiments have documented a prolonged CT in weight-trained subjects relative to active controls (1,26), and in a comparable longitudinal animal model, hypertrophied muscles of the weight-lifting cat have exhibited greater twitch durations than their contralateral control muscles (17). The mechanisms that might be responsible for these peripheral adaptations are not clearly known, and hypertrophy alone cannot account for all contractile changes. Within the limits of our experimental results, it is speculative but nevertheless interesting to suggest that ballistic training should have modified the kinetics of excitation-contraction coupling, therefore including intracellular calcium movements. Further investigations are necessary in this direction. Twitch contractile properties related to relaxation (i.e., half relaxation time and maximal rate of relaxation) were consistently modified in the present study, suggesting a greater plasticity of the descending portion of the twitch in comparison with the build-up. This seems reasonable because we asked our subjects to relax their knee extensors as fast as possible when MVC was attained. To the best of our knowledge, in typical isometric training protocols, the rate of force relaxation is not reported so that no comparison seems feasible with the present findings. In future investigations, much emphasis must be put on the rate of force relaxation during isometric contractions.

This study compared the differential effects of progressive versus brief ballistic isometric contractions during 7-wk resistance training of the knee extensors. Although voluntary torque gains were similar between the two conditions, results obtained on the evoked action potential and on the resulting twitch suggested that the adaptations took place at different peripheral levels of the neuromuscular system. Both forms of training did not modify the surface EMG

RMS activity at the training angle, and therefore the hypothesis of an increased central neural drive was rejected. Progressive training affected the vastus lateralis membrane electrical activity and ionic processes, and thus the peripheral portion of the nervous system. On the other hand, isometric training performed with ballistic contractions modified twitch contractile properties, indicating a selective adaptation of the knee extensor muscles properties (e.g., hypertrophy and/or modifications in excitation-contraction coupling kinetics). In addition, the hypothesis of a reduced coactivation in hamstrings after both forms of isometric resistance training must be considered, although it was not checked with the present methodology.

In conclusion, this study provides evidence that knee extensor muscles specifically adapt their neuromuscular properties to the type of rate of contraction performed during isometric resistance training. Our findings draw attention to the fact that progressive versus ballistic isometric contraction must be carefully defined throughout the training protocols.

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