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Effects of different strength training regimes on moment and power generation during dynamic knee extensions

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Abstract. This study examined the effect of different training regimes on moment and power generation during maximal knee extensions at low to very high extension velocities (0–1000°·s^{-1} individual range). A group of 24 soccer players performed 12 weeks of progressively adjusted strength training of the knee extensors at either high resistance (HR, $n=7$), low resistance (LR, $n=6$), loaded kicking movements (FU, $n=6$), while one group served as controls ($n=5$). Moment and power generation of the knee extensors were determined before and after the training period with a nonisokinetic measuring method recently described. Following HR training, knee extension moment increased 9%–10% at knee angular velocities 0 (isometric) and 30°·s^{-1} ($P<0.05$), peak moment increased 20% at 240–300°·s^{-1} ($P<0.05$), while power generation increased 5%–29% at 240–480°·s^{-1} ($P<0.01$). In addition, in the HR group maximal recorded power increased 45% ($P<0.01$). After FU training a 7%–13% increase in moment and power was observed at 30–180°·s^{-1} ($P<0.05$). Following LR training, peak moment increased 9% at 120°·s^{-1} ($P<0.05$). Improvements in knee extension moment and power were generally related to the angular velocities employed during training. However, as evaluated using the present measuring method, moment and power increased not only at very low but also at high knee angular velocities following the high-resistance strength training.

Key words: Knee extensors – Force-velocity – Power-velocity – Strength training

Introduction

The relationship between the velocity used during training and changes in muscle strength has been examined by several authors. In some studies, increases in peak moment and constant-angle moment have been observed at or close to the velocity used during training (Moffroid and Whipple 1970; Caiozzo et al. 1981). Other studies have demonstrated increases in extension moment at velocities equal to or lower than the specific velocity of training (Lesmes et al. 1978; Costill et al. 1979; Coyle et al. 1981). In all these studies knee extension moment was obtained by using isokinetic dynamometers at knee angular velocities not exceeding 250°·s^{-1}, which has been shown to correspond to only one-third of the maximal velocity reached during unloaded knee extension (Houston et al. 1988). Therefore, it remains unclear how strength training will influence the force generation over a full physiological range of extension velocities. Recently, we have described a method to determine muscle strength at knee angular velocities ranging from 0–1000°·s^{-1} (Aagaard et al. in press). In the present study, this method was used to determine the moment-velocity and power-velocity relationships of the knee extensor muscles in elite soccer players, before and after different types of strength training. The training was performed as isolated knee extension exercise at:
1. High resistance and correspondingly low speed or
2. Low resistance and correspondingly high speed or
3. A loaded kicking movement mimicking the muscle function during ball kicking.

Methods

Subjects. A group of 24 male elite soccer players, recruited from soccer teams ranked within the 40 best teams in the Danish league, volunteered to participate in the study. The subjects, all free from previous knee injuries, gave their informed consent to the conditions of the experiments and training procedures. Mean age, body mass and body height for all the subjects were 23.0 (SEM 0.7) years, 71.5 (SEM 1.6) kg and 179.4 (SEM 1.0) cm.

Training. The subjects were randomly assigned to four groups. Three groups performed strength training at either high resistance (HR group, $n=7$) or low resistance (LR group, $n=6$ and

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FU group, $n=6$) while the last group served as controls (CO group, $n=5$). Training took place three times a week over a 12-week period. The HR group and the LR group performed four sets of isolated bilateral knee extension-flexion movements at each training session using a hydraulic resistance device (Unilateral Quad/Ham model 507, Hydra-Fitness Inc., Belton, TX, USA). In the HR group an 8-repetition maximum (RM) load was used involving angular velocities of 20–50$°\cdot s^{-1}$. In the LR group, a 24-RM load was used involving angular velocities of 100–200$°\cdot s^{-1}$. The FU group trained the preferred kicking leg in a loaded kicking movement using a custom-built pulling device. The resistance applied corresponded to approximately 16-RM and four sets were performed each training session. Knee angular velocity varied unrestrictedly between 0 and 400$°\cdot s^{-1}$ during the kicking movement. A wire from the pulling device was at floor level attached to the foot of the subjects by a firm strap. The strapping allowed unrestricted movement at the ankle joint and the kicking movements performed closely resembled actual ball kicking. The initial training loads and number of repetitions were chosen to ensure an equal total work load in all three training groups. Training loads were progressively adjusted throughout the period of training. All training was supervised and strictly controlled.

Strength measurements. Strength measurements were conducted prior to and within 3 days after the training period. The measuring device and methodology have previously been described in detail (Aagaard et al. in press). Briefly, a flywheel system was used to provide external loading of the knee extensor muscles during dynamic (non-isokinetic) knee extensions, at joint angular velocities up to 1000$°\cdot s^{-1}$. Knee extension moment (M_{knee}) was calculated as $M_{knee} = M_{sg} + M_{grav} + M_{inertia}$, where M_{sg} was the extension moment generated to accelerate the flywheel system, M_{grav} was the moment opposing the gravitational forces and $M_{inertia}$ was the moment generated to accelerate or decelerate the lower limb. For each separate extension trial performed by each subject the following parameters were identified: (1) peak moment (M_{peak}), (2) peak power (P_{peak}), (3) peak velocity (v_{peak}), (4) moment at 50° knee joint angle (M_{50}) and (5) power at 50° knee joint angle (P_{50}), as well as the corresponding velocity, moment and power. Also, each subject's maximal parameters (maximal recorded M_{peak}, P_{peak}, M_{50}, P_{50} and v_{peak}) were identified. Force and knee angular velocity varied unrestrictedly throughout the movement of extension, and an interpolation procedure was employed to obtain moment and power at standardized velocities of 30, 120, 180, 240, 300, 360, 480, 600 and 720$°\cdot s^{-1}$ (for details see Aagaard et al. in press).

Statistics. Pre- and post-training differences between the groups were statistically tested by the Kruskal-Wallis analysis of variance for unpaired samples (Siegel and Castellan 1988). Pre- and post-training differences within each group were tested by the Wilcoxon signed-rank test for paired samples. A 5% level of significance was used.

Results

Muscle strength

For each training group, average curves are shown over the velocity range covered by all the subjects in the group (Figs. 1–4).

For the HR group M_{peak} at 0$°\cdot s^{-1}$ (isometric, $P<0.05$) and at velocities of 240 and 300$°\cdot s^{-1}$ ($P<0.01$) were increased by 10% after the period of training (Fig. 1): Also, M_{50} increased 14% at 0$°\cdot s^{-1}$ and 9% at 30$°\cdot s^{-1}$ ($P<0.05$; Fig. 2). P_{peak} increased 5%–29% at velocities 180 ($P<0.05$) and 240–360 ($P<0.01$, Fig. 3). P_{peak} also increased at 480$°\cdot s^{-1}$ for the subjects able to reach this velocity [$n=5$, $P<0.05$, 879 (SEM 121) vs 1117 (SEM 140) W, not shown in Fig. 3]. P_{50} increased 7%–17% at 180 ($P<0.05$), 240–300 ($P<0.01$) and 360$°\cdot s^{-1}$ ($P<0.05$; Fig. 4). At v_{peak} between 300 and 480$°\cdot s^{-1}$ the corresponding moment and power increased 24%–42% and 18%–32%, respectively ($P<0.01$). Also, maximal recorded power increased by 45% ($P<0.01$) from 882 to 1281 W. In the trials at which maximal velocity was found, an increase of 24% was observed in M_{peak} ($P<0.01$).

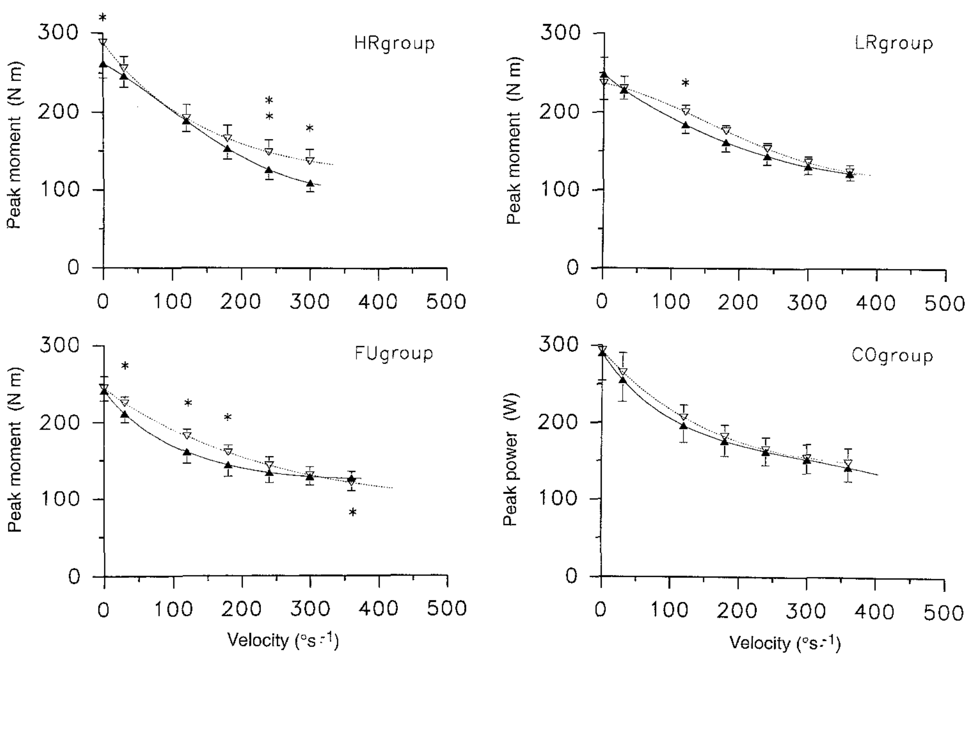

Fig. 1. Peak moment-velocity relationship before (*full line*) and after (*dotted line*) strength training. *Triangles* denote values at velocities chosen for analysis. *Error bars* SEM. Pre to post-training difference, * $P<0.05$, ** $P<0.01$. Three groups performed strength training at either high resistance (*HR*) or low resistance (*LR* and *FU*), the last group was the control group (*CO*)

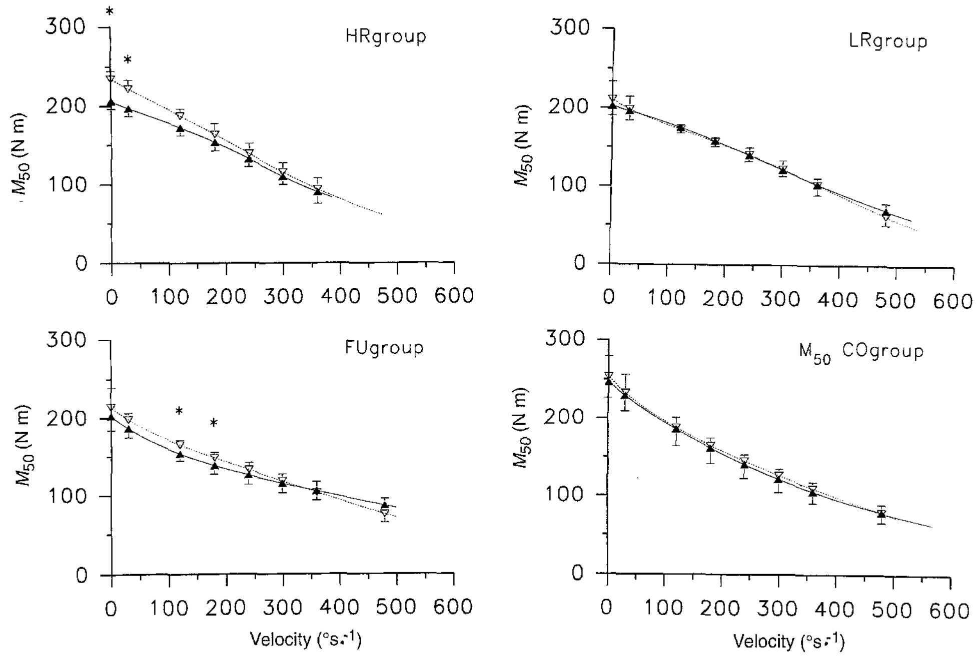

Fig. 2. Moment-velocity relationships at 50° knee joint angle (M_{50}) before (*full line*) and after (*dotted line*) strength training. Pre to post-training difference, * $P<0.05$, ** $P<0.01$. Definitions of groups given in Fig. 1

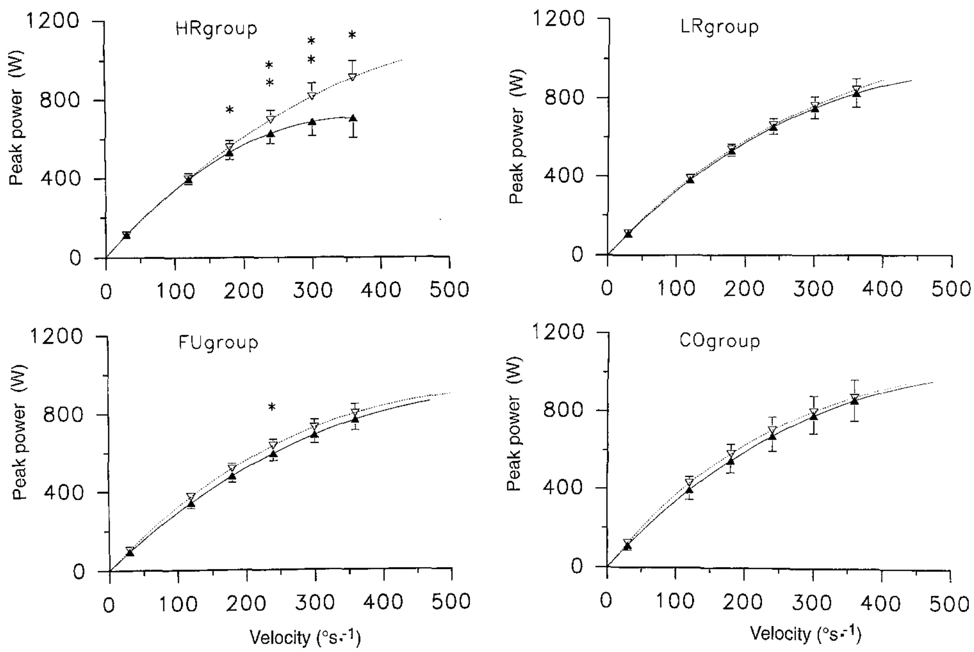

Fig. 3. Peak power-velocity relationships before (*full line*) and after (*dotted line*) strength training. Pre to post-training difference, * $P<0.05$, ** $P<0.01$. For definitions of groups see in Fig. 1

For the FU group M_{peak} increased 7%–13% at 30, 120 and 180°·s^{-1} ($P<0.05$; Fig. 1) while M_{50} increased 9% at 120 and 180°·s^{-1} ($P<0.05$; Fig. 2). P_{peak} increased 7% at 240°·s^{-1} ($P<0.05$; Fig. 3). P_{50} increased 9%–11% at velocities of 30, 120 ($P<0.01$) and 180°·s^{-1} ($P<0.05$). However, P_{50} decreased 13% at 600°·s^{-1} for the subjects able to reach this velocity [$n=5$, $P<0.05$, 757 (SEM 99) vs 656 (SEM 122) W, not shown in Fig. 4].

For the LR group, M_{peak} increased 9% at 120°·s^{-1} ($P<0.05$; Fig. 1). No changes were observed for any other parameters.

No changes were observed in the CO group.

Discussion

The major finding of the present study was that strength training at high resistance (and correspondingly low velocity) improved the mechanical performance of the extensor muscles, not only at low velocity but also at high extension velocity. In the other training groups increases in knee extension strength were limited to the specific velocities employed during training.

The improvements of knee extension power and M_{peak} at velocities of 240–480°·s^{-1} induced by the high-resistance strength training may seem surprising

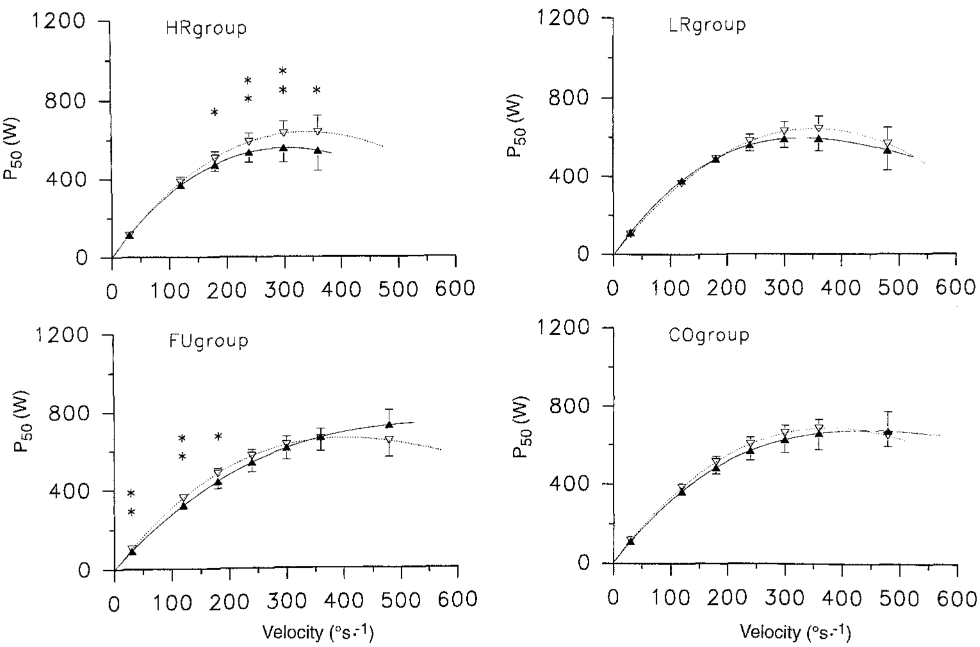

Fig. 4. Power-velocity relationships at 50° knee joint angle (P_{50}) before (*full line*) and after (*dotted line*) strength training. Pre to post-training difference, * $P<0.05$, ** $P<0.01$. For definitions of groups see in Fig. 1

in the light of the much lower training velocity of 20–50°·s^{-1}. However, high-resistance training has been shown to improve the velocity of maximal unloaded movements (Smidtbleicher and Bührle 1987; Voigt and Kausen 1990) as well as the maximal rate of isometric force development (Thorstensson et al. 1976; Smidtbleicher and Bührle 1987). An increased rate of force development and thereby higher acceleration capacity may have been the cause of the increases in moment and power observed at high velocity in the present study, since angular acceleration, or rather $M_{inertia}$, is the major component of nonisokinetic knee extension moment at high to maximal speed (Aagaard et al. in press). With the nonisokinetic measuring method presently used, an increased rate of force development would also have resulted in reaching a given level of muscle force earlier in the range of movement, i.e. closer to the optimal muscle length. This would have been most pronounced at high extension velocity, which may explain the increasing pre to post-training difference in moment and power with increase in velocity (Figs. 1, 3, 4). As has been reported elsewhere, the proportion of type IIb fibres in vastus lateralis, muscle of the same subjects (HR group) increased from 5% to 15% ($P<0.01$; Andersen et al. 1994). Due to the short time to peak tension that has been shown in type IIb fibres (Saltin and Gollnick 1983), the increase in type IIb fibre percentage may have contributed to the increase in acceleration capacity suggested above.

Apart from the findings discussed above, gains in strength were generally observed at the specific velocities used during training. After the high-resistance strength training at angular velocities of 20–50°·s^{-1} significant increases M_{50} and M_{peak} were observed at correspondingly low velocities. After low resistance strength training M_{peak} increased at 120°·s^{-1} in accordance with a training velocity of 100–200°·s^{-1}. Following the functional training, increases in moment and power were observed at 30, 120 and 180°·s^{-1}. With this training, the specificity of velocity was more difficult to evaluate as the velocity changed continuously throughout the kicking movement. However, it seems reasonable to assume that during the kicking movement peak muscle tension was primarily exerted at slow to medium knee angular velocity. The present findings of improvement in knee extension moment and power being related in general to the specific angular velocities employed during training are in agreement with previous studies which have been based on measurements of isokinetic knee extension moment (Moffroid and Whipple 1970) and power (Tabata et al. 1990).

During strength training the initial increase in strength has been ascribed to an enhancement of neural factors with morphological factors additionally contributing to the more long-term increases observed (Moritani and deVries 1979; Jones and Rutherford 1987; Narici et al. 1989). In the present study, the relatively short period of training suggested that the gains observed in moment and power were primarily due to neural changes. In support of this, most of the present strength gains were seen at the specific velocity used during training. However, as evaluated with the present measuring method, moment and power increased not only at very low but also at high knee angular velocities following the high resistance strength training. On more speculative terms, this latter finding was suggested to be a possible consequence of morphological changes and/or increase in rate of force development induced by the high resistance strength training.

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