Effects of isokinetic training of the knee extensors on high-intensity exercise performance and skeletal muscle buffering

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Abstract. Twenty-three subjects isokinetically trained the right and left quadriceps femoris, three times per week for 16 weeks; one group (n=13) trained at an angular velocity of 4.19 rad·s⁻¹ and a second group (n=10), at 1.05 rad·s⁻¹. A control group (n=10) performed no training. Isometric endurance time at 60% quadriceps maximum voluntary contraction (MVC), mean power output and work done (W) during all-out cycling, and the muscle buffer value (B) and carnosine concentration of biopsy samples from the vastus lateralis, were all assessed before and after training. The two training groups did not differ significantly from each other in their training response to any of these variables (P<0.05). No significant difference in either 60% MVC endurance time or impulse [(endurance time × force) at 60% MVC] was observed for any group after the 16 week period (P>0.05). However, the post-training increase (9%) in W during high-intensity cycling was greater in the training group than in the control group (P=0.04). Neither B nor carnosine concentration showed any significant change following training (P=0.56 and P=0.37, respectively). It is concluded that 16 weeks of isokinetic training of the knee extensors enables subjects to do more work during high-intensity cycling. Although the precise adaptations responsible for the improved performance have yet to be identified, they are unlikely to include an increase in B.

Key words: Isokinetic training – Knee extensors – High-intensity exercise – Muscle carnosine – Muscle buffering

Introduction

The acute muscle metabolite changes induced by typical sprint (Boobis et al. 1983; Cheetham et al. 1986; Jacobs et al. 1987) or strength (Costill et al. 1979; Tesch et al. 1986) training sessions indicate that the energy requirements of such are met primarily by utilisation of local ATP and phosphocreatine (PCr) stores and anaerobic glycolysis. The greater the number of high-intensity repetitions performed per set, and the shorter the intervening recovery periods, the greater the expected contribution from anaerobic glycolysis. This type of activity is generally associated with the development of a marked local muscle fatigue, as evidenced by the continually declining force or power output with successive contractions (Tesch et al. 1986). Repeated presentation of this type of stimulus results in adaptations within the muscle which may provide an improved resistance to fatigue, and thus the achievement of more work, during the performance of high-intensity exercise (Hainaut and Duchateau 1989). It has been suggested that part of the training effect might include an increase in the muscle buffer value (B), which would act to moderate the degree of acidosis developed during intense exercise (Hainaut and Duchateau 1989).

Cross-sectional studies have indicated that B of sprint-trained athletes exceeds that of endurance or middle-distance trained individuals and untrained controls (Parkhouse et al. 1985; Denis et al. 1992), but longitudinal studies examining the trainability of B have been inconclusive (Bevan et al. 1985; Sharp et al. 1986; Bell and Wenger 1988; Nevill et al. 1989; Mizuno et al. 1990). Two longitudinal studies have reported an adaptive response of the muscle’s physicochemical (in vitro) B (Bell and Wenger 1988; Mizuno et al. 1990). However, there is reason to believe that the data of one of these studies (Mizuno et al. 1990) may have been subject to error, as the reported non-bicarbonate B (approximately 300–400 mmol H⁺·kg⁻¹ dry muscle·unit⁻¹ pH) was almost double those to be expected from the known concentration, and buffering...
power, of the muscles’ constituent physicochemical buffers. This may have been the result of the very dilute nature of the homogenate used, which is known to increase the measured $B$ (unpublished observations; Nevill et al. 1989). In the other study (Bell and Wenger 1988) significant training-induced improvements in performance were reported in association with an increase in the vitro $B$. However, in this one-legged sprint-training study, a significant increase in work done by the untrained leg was also observed, in the absence of any change in the corresponding $B$. This somewhat weakens the argument for cause and effect, in relation to the buffering and performance adaptations observed in the trained leg.

None of the studies that report a training-induced elevation of the in vitro $B$ have managed to identify the component responsible for the increase. The major components which contribute to physicochemical buffering in vertebrate skeletal muscle include bicarbonate, inorganic phosphate, the dipeptides carnosine and anserine (histidine residues), and protein (histidine and cysteine residues) (Hultman and Sahlin 1980; Heisler 1986). Of these, it has been suggested that the histidine-containing dipeptides are the constituents which are most free to vary, and both within and between species, account for the majority of the variance in the measured $B$ (Marlin 1989; Sewell et al. 1991). Normal human muscle has a much lower carnosine concentration than that of other athletic species (Marlin et al. 1989; Mannion et al. 1992a) and, although higher in the muscle of sprint-trained athletes than endurance trained or untrained individuals (Parkhouse et al. 1985), it is not known how responsive this component is to long-term training, or how physiologically significant any such adaptations would be in relation to total muscle buffering and exercise performance.

The present study was carried out to examine the effect of repeated, high-intensity isokinetic training with a high work:relief ratio, on $B$, muscle carnosine concentration and exercise performance.

Methods

Subjects. Thirty-three healthy, physically active (but not specifically trained) human volunteers (19 male, 14 female) took part in the study, which was approved by the local ethical committee. Each was informed of the purpose and potential risks of their involvement before written voluntary consent was obtained. The subjects were randomly assigned to one of three groups: control (C, $n=10$), training at 4.19 rad s$^{-1}$ (TF, $n=13$) or training at 1.05 rad s$^{-1}$ (TS, $n=10$). The physical characteristics of the subjects are shown in Table 1. Subjects trained on an isokinetic knee extension machine (Orthotron KT2, Cybex) 3 days per week for 16 weeks, performing (with right and left legs alternately) either six sets of 25 maximal repetitions with 30 s rest between sets (group TF) or five sets of 15 maximal repetitions with 40 s rest between sets (group TS). Group TF performed twice as many repetitions in each session as group TS, in an attempt to maintain the same total work output for each group (Rosler et al. 1986).

Performance measurements. The tasks employed in the assessment of high-intensity exercise capacity differed from those used in training in order to minimise the influence of neural adaptations, specific only to the training mode. Nonetheless, all tasks demanded intense muscle contraction, and were expected to provide a similar metabolic challenge to the muscle.

Isometric endurance. Isometric endurance of the knee extensors was measured as the time for which 60% maximum voluntary contraction (MVC) could be maintained to fatigue. MVC was determined with both hip and knee joints flexed to 1.57 rad, as described previously (Mannion et al. 1992b). Briefly, the maximum reproducible force that could be sustained for 1–2 s was recorded on a high precision load cell, ampliﬁed via a high-gain strain gauge amplifier and displayed on a pen recorder. The force corresponding to 60% MVC was marked on the pen recorder which subjects observed constantly throughout the test. A stop-clock was started as soon as the target force was reached and stopped when the force declined by greater than 5% of the target level. The results were expressed as endurance time to fatigue and impulse [(endurance time x force) at 60% MVC].

Dynamic high-intensity exercise capacity. Subjects performed a series of modified Wingate Anaerobic Tests, on a mechanically braked cycle ergometer (Monark 864), according the method described by Mannion and Jakeman (1986). Briefly, the test began with the subject pedalling steadily at 60 rev min$^{-1}$ against a resistive force of 15 N. After a count-down, the full load (see below) was introduced and the subject pedalled with an all-out effort until instructed to stop, which was when the pedal speed had consistently decreased to less than 60 rev min$^{-1}$. The test was carried out on a daily basis, each day using one of six randomly assigned resistive loads expressed in relation to quadriceps MVC (9, 10, 11, 12, 13 and 14% MVC). (The absolute loads employed in the tests were unchanged (9, 10, 11, 12, 13 and 14% MVC). (The absolute loads employed in the tests were unchanged pre- to post-training.) Flywheel velocity was determined by a photo-optic sensor, capable of resolving every 0.05 rad turn of the flywheel, interfaced to a microcomputer (Acorn, BBC). Sampling was carried out at 25 Hz. The raw data were edited to include only those acquired whilst the pedal speed was 60 rev min$^{-1}$ or greater, with the full resistive load applied. Corrected power, i.e. with the inertial properties and acceleration/deceleration of the flywheel taken into account (Coleman et al. 1986), was computed for 4–s periods. Work done ($W$) was taken as the product of the mean power output (mean $W$) and the test duration ($t$).

Habituation. Subjects were fully habituated to all the performance tests prior to assessment and commencement of training. This involved the performance of up to five 60% MVC endurance tests, and three to four sprint cycle tests against a resistive load of 10% MVC (each test on a separate day). The performance measures from the final two habituation trials were analysed for their reproducibility (one-way ANOVA with repeated measures followed by determination of the reliability coefficient, $R$ (Safrit 1981). $R$ was extremely high for each performance variable: quadriceps 60% MVC endurance time, $R=0.95$; sprint cycle mean $W$, $R=0.96$; $W$, $R=0.97$; and $t$, $R=0.96$.

Table 1. Mean (SD) of physical characteristics of the subjects

<table>
<thead>
<tr>
<th>Group</th>
<th>Subjects</th>
<th>Age (years)</th>
<th>Height (m)</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (C)</td>
<td>4M</td>
<td>24.3 (1.3)</td>
<td>1.80 (0.11)</td>
<td>83.7 (17.8)</td>
</tr>
<tr>
<td></td>
<td>6F</td>
<td>25.5 (11.3)</td>
<td>1.67 (0.07)</td>
<td>64.2 (8.2)</td>
</tr>
<tr>
<td>Training at</td>
<td>7M</td>
<td>21.3 (1.8)</td>
<td>1.81 (0.06)</td>
<td>82.7 (9.1)</td>
</tr>
<tr>
<td>4.19 rad s$^{-1}$ (TF)</td>
<td>6F</td>
<td>21.2 (3.1)</td>
<td>1.66 (0.07)</td>
<td>59.4 (4.8)</td>
</tr>
<tr>
<td>Training at</td>
<td>8M</td>
<td>22.3 (4.9)</td>
<td>1.78 (0.06)</td>
<td>72.9 (9.4)</td>
</tr>
<tr>
<td>1.05 rad s$^{-1}$ (TS)</td>
<td>2F</td>
<td>18.5 (0.7)</td>
<td>1.69 (0.06)</td>
<td>70.4 (12.7)</td>
</tr>
</tbody>
</table>

a M, male; F, female
b Three women, originally in group TS, withdrew from the study during the first month