The Effect of Training Intensity on Voluntary Isometric Strength Improvement

The effect of different training intensities on maximum voluntary isometric contraction (MVIC) strength was examined in a three week voluntary isometric exercise programme. Eighteen healthy university students were randomly assigned to one of three training groups: Low Intensity (LI), High Intensity (HI) and Maximal Effort (ME) groups. The LI and HI groups trained by producing voluntary isometric knee extension torques equivalent to 25% and 50% of MVIC strength, respectively. The ME group produced maximal effort contractions during training.

Only the HI and ME groups demonstrated significant (p < .05) isometric strength gains. The HI group produced the greatest strength gain (45.8% of MVIC), followed by the ME group (31.3%) and the LI group (22.3%). No significant strength retention, cross transfer or isokinetic strength improvement were seen in any group. The strength improvements were of the same magnitude as those previously obtained using electro-motor stimulation at equivalent training intensities.

Strength development using resistance exercise has been a popular component of treatment in the clinical setting for many years (see Clarke 1973 and Atha 1982 for reviews). In particular, isometric exercise training is frequently used in the rehabilitation of weak or atrophied muscle. Isometric quadriceps exercise has been shown to limit muscle atrophy in patients following ligamentous surgery of the knee (Eriksson and Haggmark 1979, Godfrey et al 1979). The static nature of the contraction is advantageous in situations where joint movement is not indicated and therefore isometric exercise often precedes isotonic and isokinetic exercise.

Important factors to be considered in establishing an effective exercise training regime include the training intensity, the number and duration of contractions, and the number and frequency of training sessions. Training intensity is one of the most important parameters affecting the strength improvement resulting from training (Atha 1982). Training intensity for isometric exercise is usually defined in terms of the amount of force or torque produced by an isometric muscle action and expressed in relation to the force or torque produced in a maximal voluntary isometric contraction (MVIC). This definition is adopted in the present study.

A wide range of studies have reported strength gains following voluntary exercise. However, comparatively few of these studies have concentrated on voluntary isometric exercise (see Atha 1982 and McDonagh and Davies 1984 for reviews). A range of submaximal training intensities, from 25 to 80% of MVIC strength, have been used for training (Muller 1957, Carick and Larson 1958, Cotten 1967). The magnitudes of strength changes reported in these studies have been variable, and there has been no general agreement on the training intensity most effective for producing isometric strength gains.

More recent studies have favoured the use of ‘maximal effort’ for exercise training. Grimby et al (1973) and McDonagh et al (1983) trained subjects using 30 maximal effort contractions daily, and reported 32% and 20% increases in MVIC strength, respectively. McDonagh and Davies (1984) summarized the findings of several recent studies that have utilized maximal voluntary isometric contractions for training. Some of these studies involved 3-5 contractions per day while others involved as many as 30-42 contractions. The number of repetitions may affect the individual’s ability to generate a ‘maximal’ torque each time. It is apparent that significant differences in the training loads exist in the various studies. If the training intensity was recorded and expressed in terms of a common denominator, such as percentage of MVIC strength, it would be much easier to compare the studies directly. Studies comparing various exercise training modes such as isometric, isotonic and electro-motor stimulation have also suffered from the lack of standardization and documentation of training intensities (Singer et al 1987).

Aside from the overall gain, the retention of strength is also an important consideration in determining the value and efficacy of exercise training in the clinical setting. If the strength improvement from exercise training is only transient, then its value in the rehabilitation of muscle function may be questionable. This area certainly...
warrants more research and findings from previous studies need to be substantiated.

The ability to transfer a learned skill from one part of the body to another previously untrained part is well known as the 'transfer of learning', or the 'cross transfer effect' (Bray 1928, Oxedine 1968). The cross transfer of strength gains from an exercised contralateral homologous muscle has been the subject of research for many years. Hellebrandt et al. (1947) observed that unilateral exercise of the quadriceps muscles against heavy resistance produced a significant cross transfer effect. Moritani and deVries (1979) provided further evidence for the cross transfer effect using a progressive resistance exercise program to train the elbow flexor muscle group. They also demonstrated that the strength gain was produced in the absence of muscular hypertrophy or electromyographic changes, thus supporting the important role of neural factors in strength development.

In recent years there has been a growing interest in the use of electromotor stimulation (EMS) to improve muscle strength in humans. In 1977, Kots suggested that EMS could produce a greater strength training effect in elite athletes than voluntary exercise alone. He claimed that high intensity currents could elicit forces 10 to 30% greater than the forces produced in a MVIC (cited in Halbach and Strauss 1980, and Kramer and Mendryk 1982). Several studies which have attempted to validate Kots's claims have produced conflicting results (see Kramer and Mendryk 1982, and Lloyd et al. 1986 for reviews).

The question of whether voluntary exercise or EMS is more effective in strength training has been a popular topic of debate in the rehabilitation literature. These studies have been extensively reviewed by Lloyd et al. (1986), Morrissey (1988) and Selkowitz (1989). Studies have compared the effectiveness of voluntary exercise and EMS in normal healthy quadriceps muscles (Laughman et al. 1983, McMiken et al. 1983, Kubialk et al. 1987). Other studies have compared EMS alone to a combination of EMS and voluntary exercise (Currier et al. 1979, Walmsley et al. 1984, Hartsell 1986). These studies indicate that EMS may be as effective as voluntary isometric exercise in producing isometric strength improvement. However, consideration must be given to the numerous variations in procedures, instrumentation and standardization of parameters and methodology employed in the different studies (Singer et al. 1987). These factors may have an important contribution in affecting the outcome of strength training programs.

One of the major concerns with the interpretation of the results from these comparative studies relates to the difficulty in equating the training stimuli between voluntary and EMS programs. These issues are discussed at length in a recent paper by Lai et al. (1988). As the training intensity is likely to be the most significant variable influencing strength gains, it is extremely important to control this factor in both voluntary and EMS training programs.

Lai et al. (1988) standardized the EMS training intensity at 25 and 50% of pre-test MVIC strength. Impressive strength gains were reported following a three-week training programme. Significantly greater strength improvement was demonstrated for the higher training intensity than for the lower training intensity with 48.5% and 24.2% gains respectively. The authors commented that it would be interesting to compare the strength gains from the EMS programme with a voluntary isometric programme using an identical training protocol.

The present study was designed to investigate the effect of isometric strength training using a specific protocol and to allow a comparison of the relative effectiveness of isometric exercise and EMS at the same training intensities, as used by Lai et al. 1988.

The study posed the following research questions:

- Do voluntary isometric exercise training produce significant gains in MVIC strength?
- Do higher training intensities of voluntary isometric exercise training produce greater strength gains than lower training intensities?
- Can the strength gain resulting from isometric exercise be retained following the completion of training?
- Does voluntary isometric exercise produce significant strength gains during isokinetic exercise at 60 degrees per second?
- Does voluntary isometric exercise produce significant strength improvement in the contralateral homologous muscle group (cross transfer effect)?
- Are the strength gains produced by voluntary isometric exercise comparable to that produced by EMS at an equivalent intensity?

Methodology

Subjects

Eighteen volunteer university students (twelve females and six males) participated in the study. The main criteria for subject selection were:

- no present or previous history of neurological or orthopaedic impairment of the lower limbs; and
- no involvement in any form of knee strengthening programme for at least one month prior to the study.

The subjects were randomly assigned into one of three groups, each group having four female and two male subjects. The three training groups were:

1. LI Group - This group trained at a low intensity equal to 25% of each subject’s MVIC strength;
2. HI Group - This group trained at a high intensity equal to 50% of each subject’s MVIC strength;
3. ME Group - This group trained at an intensity equal to each subject’s maximal effort.

Informed consent was obtained in writing from each subject after reading a document explaining the purpose and procedures of the experiment.

Instrumentation and Measurement Procedures

The Kinetic Communicator (KinCom) robotic dynamometer (Chattecx Corporation, USA) was used to
Voluntary Isometric Strength Improvement

measure and analyse muscle torque data recorded during testing and training. The calibration and testing procedures were similar to those employed by Lai et al (1988).

For each muscle testing procedure (isometric and isokinetic), three trials were completed by each subject and the greatest torque level was used as the representative value for that testing occasion. MVIC strength was measured as the peak torque generated during each contraction. Isokinetic strength was measured as the average torques produced in the concentric and eccentric muscle actions.

Experimental Protocol

The experimental protocol was similar to that described by Lai et al (1988) and was in three sections.

A Pre-test procedures

Prior to the training period, all subjects participated in three sessions of pre-test measurements (once a week for three consecutive weeks). The first session was used for familiarization and no data was recorded. The two subsequent sessions were used to determine the pre-test MVIC strength of the non-dominant and dominant limb knee extensor muscle groups. The greatest MVIC strength of the non-dominant limb was used to calculate the first week training intensities for subjects in the LI and HI groups.

For strength testing with the KinCom dynamometer, each subject was seated with the pelvis and thigh stabilized and the hip maintained at 60 degrees of flexion from neutral. The arms were crossed in front of the chest, with the back reclining against the back support. The axis of rotation of the dynamometer was aligned with the anatomical axis of rotation of the knee. The centre of the leg pad of the lever arm was positioned 10 cm above the medial malleolus.

The knee was positioned 60 degrees from full extension for the isometric strength testing. Before testing, each subject performed three sub-maximal warm-up trials. Each subject then performed three maximal isometric trials. The subjects were instructed to push as hard as possible against the leg pad for five seconds. A two minute rest period followed each contraction. The three measurements of MVIC strength were recorded by the computer and the greatest value subsequently determined. This procedure was repeated on the other limb of each subject.

For isokinetic testing, the range of movement was measured by the dynamometer from full extension to 90 degrees of knee flexion. The velocity of movement was set at 60 degrees per second. The subjects again performed three sub-maximal warm-up trials prior to testing. Three trials incorporating three continuous maximal effort concentric and eccentric muscle actions were recorded for each limb.

Data from isometric and isokinetic measurements between pre-test weeks two and three were analysed using one-way ANOVA procedures and showed no significant differences between groups and limbs. The greatest pre-test MVIC strength was then used to calculate the training intensities for the LI and HI groups for the first week.

B Training procedures

The non-dominant limb knee extensor muscle group was selected for training. Each subject completed five consecutive daily sessions of training per week for three weeks. Each session consisted of three sets of ten contractions (five seconds of torque production with five seconds recovery), with a rest period of one minute between each set of contractions. The total contraction time was 2250 seconds. The relative torque produced determined the training intensity for each group.

The subjects in the LI and HI groups were required to maintain the isometric torque at their respective pre-set training intensities, ie 25% or 50% of their individual MVIC strength. A transparency with a line to mark the subject’s target force (torque divided by lever arm length) level was placed over the screen of the computer monitor. Subjects were required to produce a knee extension force so that the force display matched the target force level. This force was maintained for approximately five seconds. Throughout the training session, the experimenter monitored the graphical and digital displays of the force readings to ensure that the required force level and duration were maintained. Subjects in the ME group did not have to trace any line on the monitor screen during training, but were required to produce and maintain maximal efforts for five seconds. The subjects were able to observe their performance on the computer monitor and were verbally encouraged to produce maximal efforts.

The MVIC strength of each subject was re-tested at the beginning of the first training session of the second and third weeks of training. Subsequently, the training force values for the LI and HI groups were adjusted (according to the new MVIC strength measurements) to maintain training intensities of 25 and 50% of MVIC strength, respectively. The ME group continued to train with maximal effort.

C Post-test procedures

Following training all subjects were re-tested for both isometric and isokinetic strength of both limbs. In the three week period following post-test measurement, the subjects were retested once a week to determine the retention of isometric strength.

Data Analysis

The data were analysed using the Statistical Package for Social Sciences, version X (SPSS X). The raw data were tested by repeated measure ANOVA to compare changes within and between groups. A repeated measure with one factor fixed design was used. The differences between pre- and post-tests, and trained and untrained limbs were evaluated. A probability level of $p = 0.05$ was accepted as the minimum level of significance for all statistical analyses.
Table 1:
Summary of the mean absolute MVIC strength (in Nm) and strength changes (in %) over the training period in the trained muscle group (*p>0.05)

<table>
<thead>
<tr>
<th>Group</th>
<th>Pre-test Strength</th>
<th>Post-test Strength</th>
<th>% Change</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>LI Group</td>
<td>138.8 (Mean)</td>
<td>169.7 (SE)</td>
<td>22.3</td>
<td>0.085</td>
</tr>
<tr>
<td></td>
<td>18.9 (SE)</td>
<td>22.5 (SE)</td>
<td>3.3</td>
<td></td>
</tr>
<tr>
<td>HI Group</td>
<td>167.9 (Mean)</td>
<td>244.7 (SE)</td>
<td>45.8</td>
<td>0.002*</td>
</tr>
<tr>
<td></td>
<td>18.1 (SE)</td>
<td>24.8 (SE)</td>
<td>7.3</td>
<td></td>
</tr>
<tr>
<td>ME Group</td>
<td>165.8 (Mean)</td>
<td>217.7 (SE)</td>
<td>31.3</td>
<td>0.013*</td>
</tr>
<tr>
<td></td>
<td>17.6 (SE)</td>
<td>19.5 (SE)</td>
<td>3.9</td>
<td></td>
</tr>
</tbody>
</table>

Results
The changes in isometric strength and percentage improvements in the trained muscle group over the three weeks of training are summarised in Table 1.

The strength changes during the training and follow-up periods are illustrated in Figure 1.

An examination of the trend of strength changes during the training period shows that both the HI and ME groups demonstrated a consistent increase from week to week. In contrast, the LI group showed improvement from week one to week two, which almost plateaued by the third week.

By the end of the first week of the follow-up period, all three groups showed a decline in strength to a level which was not significantly different from their pre-test strength. The HI group showed the least decline over the three weeks of follow-up as the strength gain decreased from 45.8% at the end of the training period to 27.8% in post-test week three.

The strength gains in the ME group were less than those seen in the HI group, even though the training intensity was greater. This may have been partly due to a fatigue factor, since it was clear that there was a marked decline in the forces produced over the thirty contractions. Figure 2 shows an example of the forces produced by a typical subject from the ME group during one of the training sessions.

The raw data were subjected to an analysis of variance, and this showed that the strength improvements in the...
Voluntary Isometric Strength Improvement

Table 2:
ANOVA summary table for the trained limb (*p<0.05)

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F Ratio</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Group</td>
<td>2</td>
<td>76266.8</td>
<td>38138.4</td>
<td>9.649</td>
<td>0.002*</td>
</tr>
<tr>
<td>Within Group</td>
<td>15</td>
<td>59358.2</td>
<td>3957.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>17</td>
<td>135724.9</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Trained knee extensors of both the HI and ME groups were significant (p<0.01). In addition, the mean increase in MVIC strength of 45.8% in the HI group was significantly greater than the 31.3% in the ME group (p<0.05). The increase demonstrated by the LI group (although an increase of 22.3%) was not significant (p<0.09).

The strength increases for the ME and HI groups were significantly greater than the increase for the LI group (p<0.01). The ANOVA for the main effect is summarised in Table 2.

Table 3:
Summary of the mean absolute MVIC strength (in Nm) and strength changes (in %) over the training period in the untrained muscle group.

<table>
<thead>
<tr>
<th>Isometric Strength of the Untrained Muscle Group</th>
<th>Pre-test Strength</th>
<th>Post-test Strength</th>
<th>% Change</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>LI Group</td>
<td>(Mean) 139.6</td>
<td>162.7</td>
<td>16.6</td>
<td>0.229</td>
</tr>
<tr>
<td></td>
<td>(SE) 11.5</td>
<td>18.0</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>HI Group</td>
<td>(Mean) 181.9</td>
<td>214.4</td>
<td>17.8</td>
<td>0.196</td>
</tr>
<tr>
<td></td>
<td>(SE) 17.4</td>
<td>21.8</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>ME Group</td>
<td>(Mean) 166.4</td>
<td>184.2</td>
<td>10.7</td>
<td>0.331</td>
</tr>
<tr>
<td></td>
<td>(SE) 12.4</td>
<td>13.8</td>
<td>1.1</td>
<td></td>
</tr>
</tbody>
</table>

Table 4:
Summary of the mean absolute MVIC strength (in Nm) and strength changes (in %) over the training period in the trained muscles (Con = Concentric work: Ecc = Eccentric work)

<table>
<thead>
<tr>
<th>Isokinetic Strength of the Trained Muscles</th>
<th>Pre-test Strength</th>
<th>Post-test Strength</th>
<th>% Change</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>LI Group (Mean Con)</td>
<td>131.2</td>
<td>133.5</td>
<td>1.75</td>
<td>0.231</td>
</tr>
<tr>
<td></td>
<td>(SE) 49.2</td>
<td>33.4</td>
<td>11.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Mean Ecc) 188.9</td>
<td>182.7</td>
<td>-3.3</td>
<td>0.532</td>
</tr>
<tr>
<td></td>
<td>(SE) 40.1</td>
<td>44.5</td>
<td>14.9</td>
<td></td>
</tr>
<tr>
<td>HI Group (Mean Con)</td>
<td>135.4</td>
<td>140.5</td>
<td>3.76</td>
<td>0.191</td>
</tr>
<tr>
<td></td>
<td>(SE) 32.7</td>
<td>34.9</td>
<td>12.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Mean Ecc) 200.1</td>
<td>208.9</td>
<td>4.39</td>
<td>0.284</td>
</tr>
<tr>
<td></td>
<td>(SE) 33.3</td>
<td>46.6</td>
<td>10.5</td>
<td></td>
</tr>
<tr>
<td>ME Group (Mean Con)</td>
<td>116.7</td>
<td>127.3</td>
<td>9.08</td>
<td>0.131</td>
</tr>
<tr>
<td></td>
<td>(SE) 38.6</td>
<td>28.1</td>
<td>9.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Mean Ecc) 189.7</td>
<td>193.4</td>
<td>1.95</td>
<td>0.351</td>
</tr>
<tr>
<td></td>
<td>(SE) 35.1</td>
<td>22.1</td>
<td>11.4</td>
<td></td>
</tr>
</tbody>
</table>

Discussion

Isometric Strength Gains in the Trained Muscle Group

Significant isometric strength gains were produced in the HI and ME groups, but not in the LI group. These findings suggest that higher training intensities (of 50% or more of MVIC strength) are more effective in the short term in producing isometric strength improvement, than lower training intensities. This result may be attributed to the greater average torque produced by subjects who trained at the higher intensities. This is in agreement with previous studies by Berger (1972), Grimby et al (1973) and McDonagh et al (1983), which showed that high-resistance isometric exercises produced significant strength gains (the 'overload principle').

Interestingly, the mean isometric strength improvement in the HI group was significantly greater than the ME group. This prompted us to examine some of the strength data from all groups which was collected over the three week training period. We were able to demonstrate that the torques produced by the LI and HI groups corresponded closely to their target training intensities (and there was no decline in torque over the 30 contractions). The ME group demonstrated a decline in torque over the 30 contractions of each training session with a mean torque which ranged from 54.2% to 78.6% of MVIC strength (Figure 2). That is, the mean training intensity of the first contractions was different from the mean intensity over three sets of ten contractions. These results demonstrate that strength gain may not be directly proportional to training intensity when the number of repetitions is high and the recovery periods brief. We believe that fatigue was a factor influencing the training intensity and the resultant strength training response, as suggested by Karlsson (1979) and Petrofsky and Phillips (1986).

Muscle biopsies obtained after periods of brief exercise have shown significant ATP and CP depletion as well as lactate accumulation (Saltin and Karlsson 1971, Saltin 1973). Karlsson (1979) suggested that both phosphagen depletion and lactate accumulation occurred predominantly in the fast twitch fibres. Petrofsky and Phillips (1986) reported that fast twitch muscle showed the greatest increase in lactate concentration and greatest depletion in glycoprotein and ATP following fatiguing isometric contractions at high tensions (greater than 50% of maximum strength). The fast twitch motor units are likely to be maximally recruited in high-resistance exercises as they are capable of generating high levels of force (Burke 1980). It has been suggested that if the muscle is not given sufficient time to recover, the fast twitch fibres will operate less effectively in subsequent contractions (Tesch et al 1983). The fast twitch motor units will therefore not receive an optimum training stimulus and may possibly be inhibited (Tesch et al 1983). If the fast twitch fibres cannot contract maximally, the overall strength gains might be somewhat less than expected. This may possibly account for the smaller increase in strength gains in the ME group in the present study. The role of muscle fatigue in strength training has not been fully investigated in the literature and more extensive research is required to better understand the relationship.

From the results of the present study, a training intensity of 50% of MVIC strength produced the greatest isometric strength gain. It is not clear to what extent the strength changes were related to the other factors, such as the contraction duration, the recovery time and the number of repetitions. Further research is required to systematically examine the relationships of the various training parameters.

Retention of Strength Gains

Previous studies that have examined strength retention following voluntary isometric exercise training have shown significant loss of strength gains in four to eight weeks (Rarick and Larsen 1958, Morehouse 1967, Hakkinen et al 1981). Komi (1986) labelled this the 'detraining' period as the mechanism of strength training is reversed. He suggested that the initial strength decrease was due to a reduction in the maximal neural activity with a gradually increasing contribution of muscle atrophy. All of the studies cited above involved training periods of eight to sixteen weeks and follow-up periods of four to eight weeks. The present study showed a rapid decline in strength gains in the three weeks following the isometric training programme for all three training groups. Since the strength improvement is only transient, a three week voluntary strength training programme may have only limited clinical value.

Cross Transfer Effect

Previous studies have demonstrated the cross transfer effect following voluntary resisted exercise (Hellebrandt et al 1947, Coleman 1969, Komi et al 1978, Moritani and de Vries, 1979). These studies involved exercise training periods from eight to twelve weeks (Coleman 1969, Komi et al 1978, Moritani and de Vries 1979). In the present study, the length of the training period may possibly account for the lack of significant strength changes in the contralateral homologous muscle group, in all three groups.

Isokinetic Strength Changes

The present study found no improvement in isokinetic strength at 60 degrees per second, following three weeks of isometric exercise training. It is generally believed that isometric exercise training specifically produces strength gains in the isometric mode (Moffroid and Whipple 1970, Sale and MacDougall 1981). However, a few studies have demonstrated some overflow from isometric exercise to slow-speed isokinetic strength (Lind 1979, Murray et al 1980).

A Comparison of Voluntary Isometric and EMS Training

The present investigation was designed to parallel the major aspects of the study of Lai et al (1988) in which the EMS training intensities were set at 25 and 50% of MVIC strength. While we acknowledge that there were some differences in the nature of electrically stimulated and voluntary contractions (eg a single fixed frequency of 50 Hz was used for EMS and voluntary contractions involved a range of firing rates), nonetheless the forces produced...
by the quadriceps muscles in each study were very similar.

At the higher training intensity (50% of MVIC strength), similar strength gains of 45.8 and 48.5% were seen for the voluntary and EMS groups, respectively. At the lower training intensity (25% of MVIC strength) gains of 22.3 and 24.2% were recorded for the voluntary and EMS groups, respectively. At the lower training intensity, the volunteer isometric exercise produced significant strength gains but also strength changes would be produced if the training intensity may produce a strength gain was demonstrated in the MTIC group. The results suggest that the clinical implications of this result of a small sample size and variability. If substantiated, the implications of this result would be that EMS is preferable as a strengthening modality when only low levels of muscle force are possible or desirable. In particular, reflex inhibition associated with acute inflammation can severely retard voluntary muscle actions (Eriksson and Hagmark 1979, Stokes and Young 1984). EMS may be used at this stage to influence reflex inhibition and facilitate voluntary control (Morrissey 1988). However, at this stage these results suggest that there are essentially no differences between the two modes of strength training when the major parameters are matched.

The results from the present study also have implications for EMS training studies which use the maximum tolerated isometric contraction (MTIC) strength as the training intensity. De Domenico and Strauss (1986) have shown that the average MTIC strength produced by a variety of stimulators ranged from 47 to 74% of MVIC strength. Therefore, an EMS training programme using MTIC strength as the training intensity may produce a strength increase similar to the ME group in the present study (assuming the same training protocol). EMS training at 50% of MVIC strength is likely to produce a superior result when using the present training protocol, and MTIC strength may not be required for effective strength gains.

The results of Lai et al. (1988) for their HI group showed that EMS training not only produced significant isometric strength gains but also produced a significant cross transfer effect, retention of strength gains and increase in isokinetic strength (concentric) at 60 degrees per second. The LI group of Lai et al. (1988) only showed improvement in the cross transfer effect. In contrast, the present study on voluntary isometric exercise training failed to produce significant improvements in the above areas.

Lai et al. (1988) suggested that the electrical stimulation; in producing sensory afferent input and activating neural pathways, may result in a raised central level of excitation and multi-segmental facilitation of the spinal motoneuron pools and the relevant cortical centres above. This may result in the overflow of facilitation to the motor units of the contralateral homologous muscle group, and may lead to the improved isokinetic performance of the stimulated muscle group.

The use of EMS solely for its cross transfer effect has major clinical implications which have not been well recognised or fully explored. In patients where voluntary contractions may not be possible, EMS may be employed to improve strength or facilitate activity of the contralateral muscle group, whereas voluntary exercise may not be successful. However, the complimentary roles of voluntary exercise and EMS in rehabilitation practice have not been well defined and require continuing research.

Conclusion

The present study demonstrated significant isometric strength gains in the HI and ME groups over a three-week voluntary isometric exercise training programme. No significant strength gain was demonstrated in the LI group. The results suggest that the relationship between training intensity and strength gain is not linear, and that strength gain will plateau and possibly diminish if the training intensity is too high. Training at 50% of MVIC strength will produce a clinically acceptable strength gain. These conclusions are only relevant to the training parameters used in this study. It is not clear whether the same strength changes would be produced if other training parameters were altered.

This study also demonstrated a significant decline of strength gains in all three groups in the three week follow-up period. No significant cross transfer effect or improvement in isokinetic strength was shown for any of the three groups.

From the comparison of the results from the present study and that of Lai et al. (1988), it can be suggested that voluntary isometric exercise produces strength gains more specifically in the voluntary mode, while EMS training possibly produces a more general effect on muscle performance. EMS may, therefore, be particularly useful in early rehabilitation.

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