Introduction

Although strength training is a widespread activity and forms an important part of training for many sports, little is known about optimum training protocols or the nature of the changes that occur with such training. For instance, the improvement in training weights appears to be appreciably larger than the increase in strength of the individual muscles used in the movement. It is generally reported that responses to training are very specific. The greatest changes accompanying strength training can be seen in the training modality such as dumbbells, barbells and machines such as multi-gym and Cybex (Sale & MacDougall, 1981). As early as the fifties era, Rasch and Morehouse (1957) reported that training was specific to the movement patterns. Their participants trained the elbow flexors in the standing position and were assessed both standing and in the supine position. The increase in performance was found to be greater in the standing position compared to the supine.

Similarly, Rutherford and Jones (1986), in a 12-week study of dynamic leg extension training showed a discrepancy between the increase in weight-lifting performance and increase in isometric strength of the quadriceps. There was almost a 100% increase in the weights that could be lifted compared to a 15% gain in maximum voluntary contractions (MVC). Baker, Wilson, and Carlyon, (1994) also reported that strength training induced changes in weight-lifting performance were unrelated to changes in isometric strength. Rutherford and Jones (1986) attributed the discrepancy to learning and co-ordination of other muscle groups involved, while Wilson and Murphy (1996) suggested that an isometric test of muscular function is not sensitive to dynamically induced training adaptations. There are many reasons why a discrepancy may arise between the changes in isometric strength and the dynamic performance of lifting the training weights, but this study will look into two aspects as follows:

Angle-length specificity

Strength gains may vary with muscle length (joint angle). The load on the muscle is not uniform throughout the training movement so that the limiting factor for lifting the weights may be strength at one particular angle. Training may increase the strength at that angle by a large amount without producing a major increase at the 90^{o} angle at which the muscle is conventionally tested under isometric conditions.

Velocity specificity

It is widely believed that training benefits are limited to the performance at, or close to, the speed used in training. The scientific rationale for this is not at all clear but it is an important point to clarify because many speed athletes believe they need to train with high speed contractions, whereas the weight of scientific opinion is that low speed, high force contractions are required for maximum strength gains.

Following a period of standard resistance training, the objectives of this study were: (i) to measure the increases in isometric strength over the range of joint angle used in the training exercise, and (ii) to measure the increases in strength of the muscle when shortening at different speeds.

Methodology

Research participants

A total of 26 participants (13 male, 13 female) aged between 18–30 years volunteered for the study. Five individuals from each gender were assigned to a control group. All participants were students of the University of Birmingham. Majority of the participants were recreationally active, but none had a history of leg strength training in the previous six months. Participants were asked to maintain their habitual levels of activity throughout the study period, gave their informed consent, completed a standard health questionnaire and none had injuries to the knee or any health contra-indications such as cardiovascular disease, low or high blood pressure.

Training and strength testing

Eighteen participants (nine male, nine female) completed eight weeks of leg extension training, three times per week. Quadriceps muscle a group of each individual was trained unilaterally using a Cybex VR2 leg extension machine. One leg was arbitrarily assigned to perform the dynamic training. Leg extension exercise was performed through a range from 120^0 of knee flexion to full extension. Participants performed four sets of eight lifts at a steady pace of about 90^0/s. A load of 80% of the maximum load that can be lifted once (1RM) was prescribed and reassessed every week. Two minutes rest was allowed between sets.

Baseline strength was assessed once per week over a three-week period prior to training. Participants were also tested during the fourth week of the training and at the end of the eight weeks. Each assessment consisted of the following:(i) isometric strength measured in the strength-testing chair with the knee flexed at 1.57 radian (90^0), where four MVCs were performed with each leg; during the last three of these electrical stimulation was superimposed to estimate the level of muscle activation, (ii) length-tension relationship, involving measurements of isometric strength at 0.26 radian (15^0) intervals from 1.05 to 1.93 radians (i.e. 60^0, 75^0, 90^0, and 105^0) of knee flexion using the Cybex II isokinetic dynamometer, and (iii) isokinetic strength testing, using the Cybex II isokinetic dynamometer at velocities of 0.78, 3.14 and 5.24 rad/s (45, 180 and 300^0/s).

Data analysis

Data were presented as means (± S.E.M). Paired Student's t-tests were used to test for significance of the change relative to baseline values. The level of significance was pre-determined at $p < 0.05$.

Results and Discussion

Weight-lifting and isometric strength

Eight weeks training resulted in a 33% increased in weight lifted. This was in accordance with previous report [e.g., Sale et al., (1992); Sleivert, Backus & Wenger, (1995)]; that revealed a 43 % increase in weight lifted. In contrast, changes in isometric strength were not as high as the increased in weight lifted, where only 6% increase was noted. These results were similar in terms of a discrepancy in the increase in weight-lifting strength and increase in isometric strength (Rutherford & Jones, 1986). As reported by Baker et al., (1994), changes in weight-lifting strength were unrelated to changes induced in isometric strength.

Table 1: Absolute 1 R-M (kg) pre and post training for trained and untrained legs and control participants. (Means ± SEM).

	Pre	**Post**
Trained leg	47.8 ± 3.1	63.4 ± 4.5 * *p < 0.05*
Untrained leg	49.6 ± 3.31	53.3 ± 3.8 * *p < 0.05*
Control	44.0 ± 5.0	44.0 ± 5.9

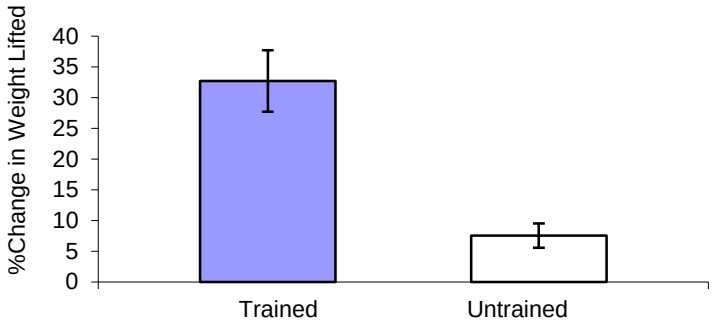


Figure 1: Percentage change in the weight lifted (1-RM) in trained and untrained leg after eight weeks of training.

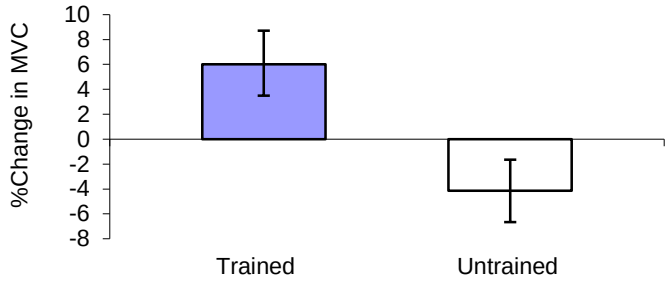


Figure 2: Percentage change in isometric MVC in the trained and untrained leg after eight weeks of training.

Angle-length specificity

In investigating this discrepancy, one of the factors examined was the angle specificity. Between 13% and 20% increases were found at all angles measured (Figure 3). As isometric training is highly angle specific (Weir, Housh, Housh, & Weir, 1995; Lindh, 1979; Thepaut-Mathieu, Van Hoecke, & Maton, 1988; Kitai & Sale, 1989), the eight weeks training might have increased strength at either the longer muscle length where the inertia of the weight must be overcome, or at the shorter muscle length where extra force is needed to overcome the biomechanical problems at the knee. But the result showed otherwise, with very similar increases at all angles tested. Thus the results indicate there are no length specific adaptations.

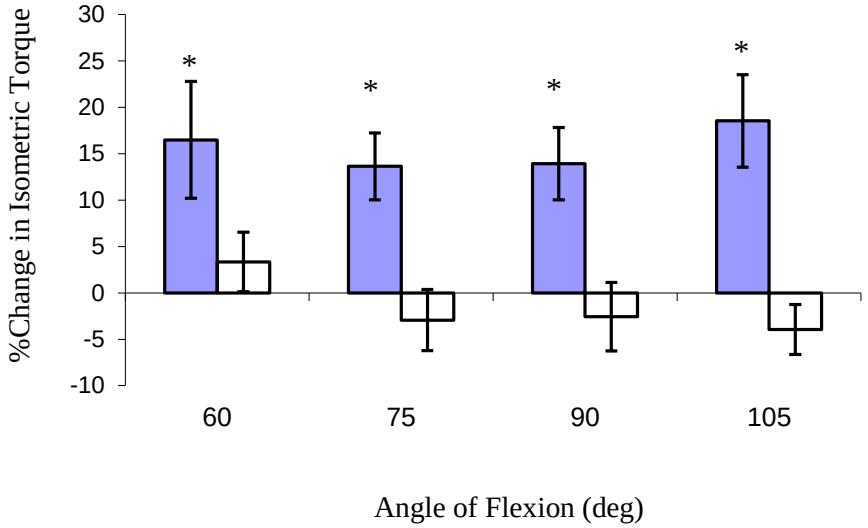


Figure 3: Percentage change in the angle-torque relationship in the trained (shaded) and untrained (clear) after eight weeks of training.

The results showed some differences in the isometric measurements made with the isometric testing chair and the Cybex dynamometer. A 6% increase in isometric strength was found using strength testing chair that was measured at an angle of flexion of 90 degrees (Figure 2). However, using the Cybex dynamometer increases of almost 14% were found at the same angle of flexion (Figure 3). This could not be explained by familiarisation, as the untrained leg did not have the same relative increase. In fact, the untrained leg showed a decrease in performance on the Cybex dynamometer (Figure 3). A possible reason may be that there is a specificity of training and testing involved. As the training was being done on a Cybex machine, the testing was also on a Cybex dynamometer, where the sitting position and the angle of the hips were similar.

Voluntary activation

It was found that on the strength testing chair, almost all the participants could activate their muscle to more than 90% (Figure 4).

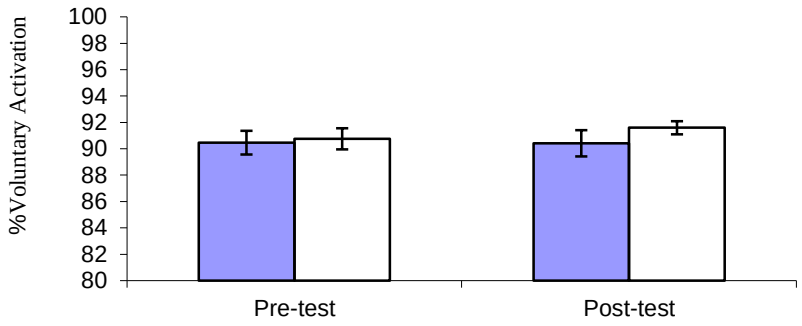
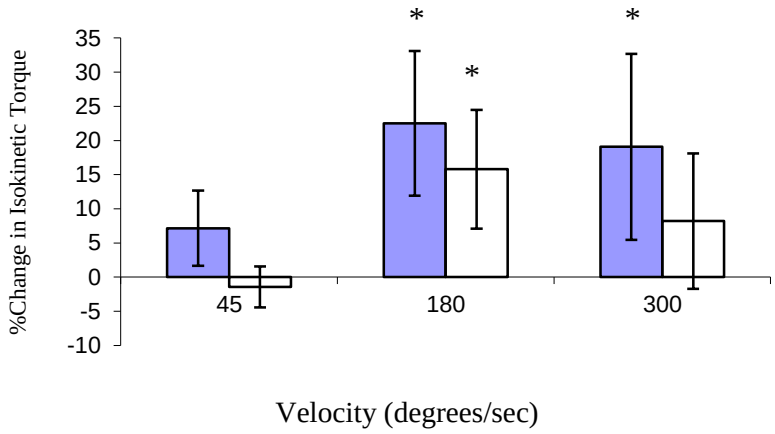


Figure 4: Voluntary activation of the trained (shaded) and untrained (clear) leg before and after training.

The post-test data from Figure 4 also showed that there was no increase in the voluntary activation of the trained leg.

Velocity specificity

The second possible reason for the discrepancy is the existence of velocity specificity. There is evidence from other studies that the greatest strength gains occur at or near the training velocities. As seen in Figure 5, a significant increase in isokinetic torque was found at 180 degrees/sec and at 300 degrees/sec. The percentage increase at 180 degrees/sec is much more than at 300 degrees/sec. It seems to demonstrate a velocity-specific transfer of strength gain as the training was done between 45 degrees/sec and 180 degrees/sec. However, according to Lesmes, Costill, Coyle, and Fink (1978) training benefits are shown only at or below the training speeds. The fact that similar changes were seen in the untrained leg suggests that any apparent velocity specificity was not related to the training gains.



* Significantly differently from the pre training value ($p < 0.05$)

Figure 5: Percentage change in isokinetic torque at three angular velocities in the trained (shaded) and untrained (clear) leg after eight weeks of training.

Conclusion

The present study suggests that the discrepancy seen in the big increase in the weight-lifting strength as compared to isometric strength cannot be accounted for by the angle specificity and velocity specificity factors. Although length specific adaptations were reported, most of these studies were with isometric training at a particular angle (Lindh, 1979; Thepaut-Mathieu et al., 1988, Kitai & Sale, 1989). The present study, which trained dynamically through the range of motion, did not show any length specific adaptations. This is in accordance with previous study by Graves, Pollock, Jones, Colvin, and Leggett (1989) which looked into length specificity and variable resistance training. Velocity specificity is generally characterized by the greatest increase in strength occurring at or near the velocity of the training exercise (Behm & Sale, 1993). However, findings did not demonstrate a velocity specific effect as in agreement with some previous studies (Thorstensson, 1977).

In the absence of a muscle-specific explanation for the discrepancy between gains in performance and isometric strength, it seems likely that some forms of neural adaptations is responsible for the difference. Future experiments may focus on the neural adaptations and therefore validating the use of EMG, and analysing its pattern and change during specific training. In addition, the role of antagonist and synergist in providing insight to the discrepancy, and also to

compare the neurogenic adaptations in skilled athletes and unskilled athletes should also be subjected to further examination.

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