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Journal of Sports Sciences, August 2005; 23(8): 817 – 824

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Strength training: Isometric training at a range of joint angles versus dynamic training

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(Accepted 9 October 2004)

Abstract

Strength training with isometric contractions produces large but highly angle-specific adaptations. To contrast the contractile mode of isometric versus dynamic training, but diminish the strong angle specificity effect, we compared the strength gains produced by isometric training at four joint angles with conventional dynamic training. Thirty-three recreationally active healthy males aged 18 – 30 years completed 9 weeks of strength training of the quadriceps muscle group three times per week. An intra-individual design was adopted: one leg performed purely isometric training at each of four joint angles (isometrically trained leg); the other leg performed conventional dynamic training, lifting and lowering (dynamically trained leg). Both legs trained at similar relative loads for the same duration. The quadriceps strength of each leg was measured isometrically (at four angles) and isokinetically (at three velocities) pre and post training. After 9 weeks of training, the increase in isokinetic strength was similar in both legs (pooled data from three velocities: dynamically trained leg, 10.7%; isometrically trained leg, 10.5%). Isometric strength increases were significantly greater for the isometrically trained leg (pooled data from four angles: dynamically trained leg, 13.1%; isometrically trained leg, 18.0%). This may have been due to the greater absolute torque involved with isometric training or a residual angle specificity effect despite the isometric training being divided over four angles.

Keywords: *Muscle strength, isometric, dynamic, isokinetic, resistance training*

Introduction

The most effective means of increasing strength by high resistance training remains unknown, despite the obvious importance of this knowledge for athletic training and rehabilitation. We have recently examined the influence of fatigue in resistance training (Folland, Irish, Roberts, Tarr, & Jones, 2002) and the effect of a bout of damaging eccentric work at the onset of a training programme (Folland, Chong, Copeman, & Jones, 2001), but these variables were not found to significantly influence strength gains.

Studies that have employed isometric contractions have often reported large and rapid increases in strength [40% in 8 weeks (Young, McDonagh, & Davies, 1985); 25 – 54% in 5 weeks (Thepaut-Mathieu, Hoecks, & Maton, 1988); 30% in 5 weeks (Lindh, 1979); 27% in 6 weeks (Weir, Housh, Weir, & Johnson, 1995)], which could suggest that this type of training is more effective than conventional dynamic training. A limitation of isometric training is that it produces highly length-specific adaptations with considerable strength increases at the training angle, but with little transfer to other muscle lengths (Kitai & Sale, 1989; Lindh, 1979; Thepaut-Mathieu *et al.*, 1988; Weir *et al.*, 1995). In contrast, dynamic training results in smaller strength increases throughout the range of the training movement (Graves, Pollock, Jones, Colvin, & Leggett, 1989).

Although there has been considerable attention to different types of muscle contractions in resistance training, few researchers have compared isometric and dynamic contractions. Duchateau and Hainaut (1984) compared maximum isometric contractions (10 × 5 s duration) with rapid dynamic contractions (100 at 30 – 40% maximum isometric force). They found clear evidence for training specificity effects, with maximum isometric training increasing force production at high loads, and rapid dynamic

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ISSN 0264-0414 print/ISSN 1466-447X online © 2005 Taylor & Francis Group Ltd
DOI: 10.1080/02640410400021783

contractions increasing velocity with low loads. However, the dissimilar level and duration of loading make direct comparison of the two types of contractions impossible.

Jones and Rutherford (1987) used similar high relative loads to compare isometric, concentric and eccentric contractions. They found significantly greater increases in isometric strength (measured at the isometric training angle) after isometric training (more than twofold) compared with concentric or eccentric contractions. Given the documented large and highly angle-specific adaptations to isometric training detailed above, this finding is not surprising. However, Jones and Rutherford also found evidence for a greater magnitude and duration of muscle activation during isometric work that may have accounted for the large isometric strength gains with this type of training.

In terms of dynamic/isokinetic strength measures, we are unaware of any studies that have contrasted isometric and dynamic training at similar relative loads, perhaps because of the highly angle-specific effects that might be expected. Furthermore, no research to date has contrasted the mode of contraction (isometric versus dynamic) independently from the length specificity adaptation. Training isometrically at a range of angles might be more effective than dynamic training, but without the concentrated angle specificity associated with isometric training at just one angle. Furthermore, this approach facilitates a genuine comparison of dynamic and isometric strength changes following these two types of contractions.

Kanehisa and Miyashita (1983a) had participants train isometrically at a range of angles for 8 weeks, but unfortunately they did not employ a comparison group that undertook conventional dynamic training. In the present study, therefore, isometric training at four different muscle lengths was compared with conventional dynamic training (lifting and lowering), using similar relative loads, and assessed by both isokinetic and isometric strength measures.

Methods

Study design

The large individual variation in the response to strength training (Carey Smith & Rutherford, 1995; Haakinen, Komi, & Tesch, 1981) makes the comparison of strength training protocols between groups of individuals difficult. In contrast, intra-individual comparisons, where opposite limbs are trained using different methods, should highlight the experimental variable. However, crossover effects that are typically ascribed to neurological adaptations may confound this type of intra-individual design (Moritani & deVries, 1979). To minimize the influence of possible crossover effects, young healthy, physically active individuals who might have less scope for changes in learning and coordination were recruited. Furthermore, to evaluate the capacity for neurological adaptation, the ability of the participants to activate the quadriceps muscle was assessed before training by the twitch interpolation technique.

Participants

Thirty-three healthy male volunteers (age 21.5 ± 2.1 years; body mass 76.5 ± 8.6 kg; height 1.81 ± 0.06 m; mean ± *s*) completed 9 weeks of knee extensor strength training. The participants were recreationally active with no history of knee or thigh injury, and had not undertaken any leg strength training during the previous 6 months. They were recruited from among the staff and students at the University of Birmingham and gave their informed consent to participate. All participants were instructed to maintain their habitual level of activity throughout the study period. The study was approved by the local ethics committee.

Training

The training consisted of three sessions per week (Monday, Wednesday and Friday) for 9 weeks and every training session was supervised. The participants trained the quadriceps femoris muscle group unilaterally. One leg of each participants was randomly assigned to dynamic training, while the other leg performed only isometric training. The order of the training (i.e. isometric or dynamic) within each training session was randomized. The training load for both protocols was set at 75% of the respective maximum lift or force for that training mode, and the maximum was re-assessed on a weekly basis.

Isometric training

A standard variable resistance leg extension machine (Cybex VR2) was adapted for isometric work. A strain gauge was placed in the tension strap and, after amplification and digitization, the signal was displayed on a computer screen in front of the participant. This allowed force to be measured with the training apparatus and provided visual feedback for each contraction. The participants completed four sets of 10 repetitions of 2 s duration, with one set being completed at each of four angles of knee flexion: 0.87, 1.22, 1.57 and 1.92 rad (50°, 70°, 90° and 110°). There was 2 s rest between contractions and 2 min rest between each set. During each training session, the sets (angles) were completed in a different random order.

Dynamic training

Weights were lifted and lowered for four sets of 10 repetitions with a variable resistance leg extension machine (Cybex, VR2). The participants were instructed to take 1 s to lift and 1 s to lower each repetition, through a range of 2.09 to 0.52 rad (120° to 30°), equating to $\sim 1.57\ \text{rad} \cdot \text{s}^{-1}$, with a short pause between lifts and 2 min rest between sets.

The variation in loading throughout the range of motion with the training machine was also assessed. Using a hand-held digital force transducer (Penny and Giles, Transducers, Christchurch, UK) placed perpendicular to the lever arm, the force required to hold a constant load (10 kg) stationary at different knee flexion angles (0.87, 1.22, 1.57 and 1.92 rad) was recorded.

Strength testing

Maximum quadriceps strength of each leg was assessed pre and post training. Pre-training strength was measured on three occasions, each 1 week apart. Post-training strength was measured twice, 3 and 5 days after the last training session. The average values from the pre- and post-training measurements were compared to evaluate the gains in strength. Three different types of strength measurements were made on each test occasion, which lasted approximately 40 min. There was 15 min rest between the dynamometer measurements (angle – torque and isokinetic) and isometric strength at 1.57 rad.

Two sets of measurements were made using a Cybex Norm isokinetic dynamometer (Lumex Inc., Ronkokama, NY, USA). The axis of the knee joint was aligned with the centre of rotation of the dynamometer arm, and the lower leg was strapped to the lever arm at the ankle. The participants were restrained at the waist, shoulders and the distal part of the thigh, and the backrest was set at 1.74 rad (100°) from the horizontal base of the seat.

Angle – torque relationship

Isometric strength was also measured at four angles of knee flexion [0.87, 1.22, 1.57, and 1.92 rad (50°, 70°, 90° and 110°)] using the dynamometer. The angles were selected in a random order for each participant and the order was maintained on successive test occasions. The participants attempted two maximal voluntary contractions of 3 s duration at each angle, with 20 s between each contraction and at least 30 s rest between each angle. During each maximal voluntary contraction, the participants received direct visual feedback of the force signal as well as verbal encouragement.

Isokinetic strength

Knee extension strength was measured at three velocities, 0.79, 2.62 and 5.24 $\text{rad} \cdot \text{s}^{-1}$ (45, 150 and $300° \cdot \text{s}^{-1}$). The participants performed three practice trials, before three maximal efforts were recorded at each velocity. There was 30 s rest between each velocity and the highest peak torque from the three trials was recorded.

Muscle activation and isometric strength at 1.57 rad

Measurements of isometric strength at 1.57 rad (90°) were duplicated with a conventional isometric strength testing chair (Parker, Round, Sacco, & Jones, 1990). This system affords measurement of muscle activation as well as being highly reliable (over the three baseline tests the coefficient of variation was 3.5% versus 6.9% for the Cybex dynamometer at the same angle).

Force was measured using a calibrated U-shaped aluminium strain gauge (Jones & Parker, 1989) with a linear response up to 1000 N. The participants performed three maximal voluntary contractions of the leg extensors with at least 30 s between each. During each maximal voluntary contraction, the participants received direct visual feedback of the force signal as well as verbal encouragement.

On one of the pre-testing occasions, electrically stimulated twitches were superimposed on three maximal voluntary contractions to estimate the level of quadriceps activation (Rutherford, Jones, & Newham, 1986). Two conducting rubber electrodes ($\sim 100\ \text{cm}^2$), with a coating of conducting gel, were applied proximally and distally to the anterior surface of the thigh. A CED-1401 (Cambridge Electronic Design Ltd, UK) triggered the electrical stimuli (pulse width 50 μs, up to 200 V; Digitimer DS7, UK) at a frequency of 1.25 Hz and twitch magnitude was manipulated by changing the current (range 28 – 50 mA). The size of the twitches during the voluntary contractions was compared with that at rest before the contraction to calculate the level of muscle activation.

Statistical analyses

The data from both dynamometers were expressed as absolute and relative changes in strength. A three-way repeated-measures analysis of variance (ANOVA, SPSS v11) was performed on the absolute isometric (time × angle × training) and absolute isokinetic (time × velocity × training) data produced with the Cybex dynamometer. Relative values from this dynamometer were compared with a two-way ANOVA for isometric (angle × training) and isokinetic measurements (velocity × training). In each case, Mauchly's test of sphericity was used to determine whether the assumption of sphericity was violated by the data. Where this did occur, the Huyn-Feldt correction was applied. When differences were found by ANOVA, Tukey's HSD test was used as a *post-hoc* test to ascertain where the difference lay.

The data recorded from the conventional strength chair were evaluated for significance differences between the training protocols using paired Student's *t*-tests. The results are expressed as the mean ± standard error of the mean unless stated otherwise and statistical significance was set at $P < 0.05$.

Results

Angle–torque relationship

The angle–torque relationships of the isometrically trained and dynamically trained legs were very similar at the start of the study (Figure 1a). Strength training, irrespective of type, significantly increased the isometric strength of the participants at a range of angles ($F_{1,32} = 115.9$, $P < 0.01$). The improvement in absolute isometric strength was significantly affected by the type of training, with greater improvements associated with isometric training ($F_{1,32} = 9.0$, $P < 0.01$). Relative gains in isometric strength were also greater for the isometrically trained than the dynamically trained leg ($F_{1,32} = 7.2$, $P < 0.01$) (Figure 1b). The percentage gains in isometric strength varied significantly depending on the measurement angle ($F_{3,96} = 11.3$, $P < 0.01$), with *post-hoc* analysis revealing gains at 1.57 rad to be greater than at 0.87 and 1.92 rad ($P < 0.01$) and gains at 1.22 rad to be greater than at 1.92 rad ($P < 0.01$).

The normalized angle–force relationship for the training machine, specifically the force required to hold a constant load stationary at different angles of knee flexion (equivalent to isometric force), displayed only a small variation throughout the range of movement (< 10% variation) (Figure 2). In contrast, the isometric angle–torque relationship demonstrated the ability of the quadriceps muscle to vary by 42% throughout the same range (Figure 1a).

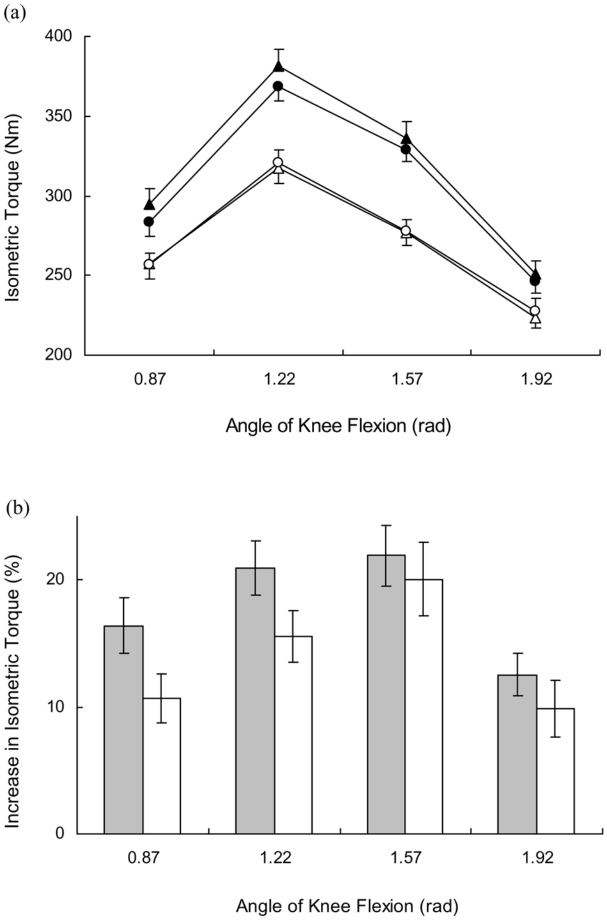

Figure 1. (a) The angle–torque relationship, before (open symbols) and after (closed symbols) isometric (triangles) and dynamic (circles) training. (b) Percentage increase in isometric strength at each angle after isometric (shaded bars) and dynamic (open bars) training (mean ± s_x).

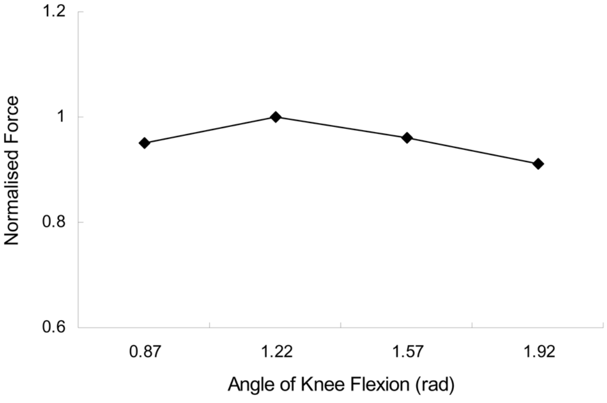

Figure 2. The normalized force required to hold a constant load stationary at different positions throughout the range of movement with the Cybex VR2 leg extension machine. Force was normalized to peak force at 1.22 rad.

Isokinetic strength

Prior to training, isokinetic strength of the isometrically and dynamically trained legs was very similar at the three measured velocities of 0.78 rad·s^{-1} (241.7 ± 6.9 vs. 240.2 ± 6.3 Nm respectively), trained leg, 240.2 ± 6.3 N·m), 2.62 rad·s^{-1} (isometrically trained leg, 175.1 ± 4.5 N·m; dynamically trained leg, 173.7 ± 4.6 N·m) and 5.24 rad·s^{-1} (isometrically trained leg, 117.8 ±

$2.62\ \text{rad} \cdot \text{s}^{-1}$(175.1 ± 4.5 vs. 173.7 ± 4.6 Nm) and $5.24\ \text{rad} \cdot \text{s}^{-1}$(117.8 ± 3.1 vs. 116.3 ± 3.3 Nm). Resistance training significantly increased absolute isokinetic strength at this range of velocities, irrespective of the type of training undertaken ($F_{1,32} = 70.6$, $P < 0.01$). The improvements in absolute isokinetic strength with training were not affected by the type of training ($F_{1,32} = 0.02$, $P = 0.99$). Neither was there an interactive effect of the type of training on the absolute isokinetic strength at particular velocities ($F_{2,64} = 1.96$, $P = 0.16$).

The type of training did not significantly influence the relative increases in isokinetic strength *per se* ($F_{1,31} = 0.05$, $P = 0.83$) (Figure 3), but did interact significantly with the gains in isokinetic strength at different velocities ($F_{2,62} = 3.6$, $P = 0.03$). However, *post-hoc* tests revealed no significant difference between isometric and dynamic training at any specific velocity.

The relative improvements in isokinetic strength were significantly influenced by the measurement velocity ($F_{2,62} = 5.6$, $P < 0.01$), and *post-hoc* analysis revealed greater strength gains at $0.79\ \text{rad} \cdot \text{s}^{-1}$ than at $5.24\ \text{rad} \cdot \text{s}^{-1}$, irrespective of the type of training ($P < 0.05$).

Muscle activation and isometric strength at 1.57 rad

During the baseline measurements, the participants were able to achieve 97.2 ± 2.1% (mean ± *s*) of full activation during maximum isometric contractions, as measured by the twitch interpolation technique. Before training, the isometrically and dynamically trained legs were very similar (647.8 ± 17.3 N and 652.8 ± 17.7 N. respectively). Both types of training elicited significant increases in absolute strength ($P < 0.001$). There was a significantly greater increase in strength for the isometrically trained leg than the dynamically trained leg (15.2 ± 1.3% and 11.5 ± 1.0%, respectively; $P < 0.001$).

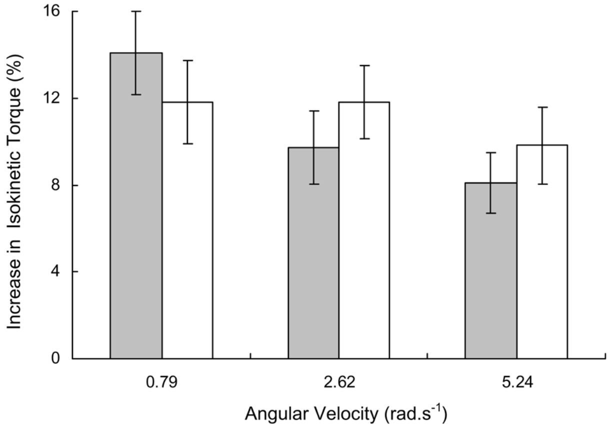

Figure 3. Percentage increase in isokinetic peak torque at three angular velocities after isometric (shaded bars) and dynamic training (open bars) (mean ± s_x).

Discussion

Both types of resistance training resulted in significant improvements in isometric and isokinetic strength. Isometric training at four joint angles did not result in the highly angle-specific adaptations that have been reported for isometric training at just one position (Kitai & Sale, 1989; Lindh, 1979; Thepaut-Mathieu *et al.*, 1988; Weir *et al.*, 1995). However, training isometrically produced significantly greater gains in isometric strength across a range of angles (assessed with two dynamometers) than training dynamically. In contrast, both types of training resulted in similar gains in isokinetic (dynamic) strength.

The current study was a first attempt to make a direct comparison between isometric and dynamic training contractions, while attempting to negate the confounding factors of differences in relative loading (magnitude and duration), and the angle specificity effect of training isometrically at just one angle. The experiment was designed so that both training protocols had an equal duration of tension at the same relative load. However, there are some issues in the control of these parameters that could have influenced the results.

First, even a small discrepancy in the duration of loading may have an accumulative effect upon strength gains, as noted by Jones and Rutherford (1987). Although every training session of each participant was strictly supervised, during dynamic training there can be a natural tendency to lift and lower the weight at a rate of greater than 2 s per lift. The authors are confident that for voluntary training the duration was matched as closely as possible.

Second, there are a number of aspects to be considered when comparing the loading of the two protocols. The intention of equal relative loading for the two protocols is clearly complicated when one considers that the dynamic training involved lifting (concentric) and lowering (eccentric) phases that have diverse force capabilities. In the current study, the intention was to match the relative loading for the lifting (concentric) phase of the dynamic training with the isometric training. As maximum isometric strength is greater than concentric strength, this matched relative loading accepted a discrepancy in the absolute level of loading. The dynamic training involved an average velocity of $1.57\ \text{rad} \cdot \text{s}^{-1}$ and the load was set relative to 1-RM, which was presumably determined by concentric lifting strength. Force–velocity data from similar subjects (Folland *et al.*, 2002) demonstrated peak concentric torque at $1.57\ \text{rad} \cdot \text{s}^{-1}$ was ~75% of peak isometric torque at the same angle ($\sim 75^\circ$ of knee flexion). Therefore, this discrepancy in absolute loading (i.e. 33% greater for the isometrically trained than the dynamically trained leg) was accepted from the onset of the study to contrast equal relative loading. As there has been little work comparing these different types of contractions, it is unclear whether it is absolute or relative loading that is the critical parameter in the training response, and in the current study which would provide the more valid comparison. An alternative methodology would be to attempt to match absolute torque in the two training protocols. This approach would clearly negate matched relative loading and might necessitate sub-optimal isometric loading in order to balance absolute torques.

Furthermore, due to the mechanics of the exercise machine used for the dynamic training, the actual dynamic training load seems certain to have been lower than intended for much of the range of movement. In the current study, we found that a modern well-engineered resistance training machine (Cybex, VR2), with a variable cam, did not adequately match the angle – torque relationship of the quadriceps muscle of the participants. It is our belief that this is commonly the case even with modern resistance training apparatus. The angle – force relationship for the training machine was very flat ($< 10\%$ variation) (Figure 2) in comparison with the muscle's ability (Figure 1a), which varied substantially (42%) throughout the same range of movement. The contrast of these two curves suggests that the greatest relative loading will be at the periphery of the range of motion – particularly at long muscle lengths where the muscle is at its weakest. It is therefore not surprising that the commonly observed "sticking point" limiting a lift is at the beginning of the movement (long muscle lengths, $\geqslant 1.92$ rad), especially when one considers that the inertia of the load must also be overcome at this point. If the maximum lift (1-RM) was limited by strength at this point, then the prescribed relative training load (75% 1-RM) is likely to only have provided the desired loading at this point, with less than the prescribed training load during the remainder of the movement. For example, as the movement progressed to an angle of 1.22 rad (70°), in contrast to 1.92 rad (110°), there is a disproportionate increase in the muscle's ability compared with the small additional torque required at this angle. It can be estimated that at 1.22 rad the same lift would equate to only 58% of maximum concentric torque, rather than the prescribed 75%. This implies that the dynamic training load may have varied between 58 and 75% of isometric training torque, according to the angle under consideration, and implies the isometric training load was 33 – 75% greater than the dynamic training load. This clearly represents a substantial discrepancy.

In an attempt to compare isometric and dynamic loading independent of angle specificity, we tried to match the relative loading of the two protocols. In retrospect, due primarily to the surprisingly flat nature of the angle – force relationship of the training machine, this was not achieved, and this accentuated the difference in absolute torque of the two training protocols. Future work would benefit from a more uniform relative loading throughout the range of motion for the dynamic training so as to accurately equate the relative loading.

The overall findings from the two dynamometers used for isometric measurement were similar (Cybex Norm and conventional strength chair: significantly greater isometric strength gains with isometric training), but in terms of the magnitude of the gains in isometric strength at 1.57 rad, there was a clear discrepancy between them (conventional strength chair: dynamically trained vs. isometrically trained leg, 11.5% vs. 15.2 %; Cybex Norm: dynamically trained vs. isometrically trained leg, 20.0% vs. 21.9%). It is not clear why there was such a difference in the magnitude of recorded strength gains (1.4 – 1.7-fold greater for the Cybex dynamometer). It may be partially attributed to the lower reliability of the Cybex (coefficient of variation: 6.9% vs. 3.5%). Most commercial dynamometers are designed primarily for rehabilitation and their padding reduces the reproducibility of positioning the participant and causes greater compliance within the measurement system. Additionally in the current study, only two maximal voluntary contractions were attempted at each angle with the Cybex, as opposed to three with the conventional strength chair. However, it is difficult to see how any difference in reliability might affect the magnitude of the strength changes.

To remove the concentrated angle-specific effects of isometric training at just one angle, four distinct yet contiguous isometric angles were selected (0.87, 1.22, 1.57 and 1.92 rad). This more diverse isometric training employed in the present study did not produce strength gains that were as large as those reported for isometric training at just one angle [e.g. 35% after 12 weeks of training (Jones & Rutherford, 1987)]. This was not surprising considering that only a quarter of the training stimulus in the present study was specific to any given angle.

The significantly greater isometric strength gains with isometric training, compared with dynamic training, could be attributed to different factors. One possibility is a residual angle specificity effect. Although the current isometric training was divided over four angles, considering the potent angle specificity effect observed with isometric training at just one angle, there may still have been a residual angle specificity effect. In particular, greater gains in isometric strength at the training angles, but smaller gains at other angles. In contrast, the dynamic training involved a larger range of motion (dynamic vs. isometric: 0.52 – 2.09 vs. 0.87 – 1.92 rad) and a more diffuse training stimulus. Unfortunately, the current study did not include isometric strength measurement at angles between or outside of the training angles, but this would be strongly advised in future research.

The greater gains in isometric strength with isometric training could be due to a contractile mode specificity effect, with isometric training producing neurophysiological adaptations specific to isometric contractions. Although there is strong evidence for a contractile mode specificity effect when contrasting concentric and eccentric training (Hortobagyi *et al.*, 1996), independent of an angle specificity effect, the authors are not aware of any evidence for a contractile mode specificity discrepancy between isometric and concentric strength.

Finally, and perhaps most likely, the higher absolute torques associated with isometric training (estimated as 33 – 75% higher) may account for the greater isometric strength gains observed. This appears to be a substantial difference, particularly as the level of loading is considered critical to the training response (Atha, 1981; McDonagh & Davies, 1984), and therefore seems a probable explanation for the greater isometric strength gains with isometric training.

The significantly greater strength gains at the mid-range angles (1.57 and 1.22 rad), irrespective of the type of training, was an unexpected finding. In terms of isometric training, it could be hypothesized that there might be transfer of strength gains at one position to adjacent angles/positions. After 6 weeks of isometric training at one angle, Weir *et al.* (1995) found significant increases in strength up to 0.52 rad (30°) from the training angle. If this were the case in the present study, the mid-range angles would exhibit the greatest strength gains as they would receive transfer effects from both adjacent shorter and longer muscle lengths. The greater gains in isometric strength at mid-range angles with dynamic training is contrary to our previous findings (Folland *et al.*, 2002) as well as the proposed rationale that the highest relative loading occurred at long muscle lengths. Our earlier study employed a similar dynamic training machine, but found significant increases in isometric strength only at the longer muscle lengths. The reason for these contradictory findings is unclear.

Overall, the increases in isokinetic strength were fairly similar for isometric and dynamic resistance training. There was no effect of the different types of training upon isokinetic strength gains *per se*, or at any specific velocity. However, from Figure 3 there appears to be a steeper drop-off in strength gains at higher velocities for the isometrically trained than the dynamically trained leg, and the pattern of isokinetic strength gains across the three velocities was significantly different according to the type of training. This is in agreement with the literature, which indicates a degree of velocity specificity in strength training (Caiozzo, Perrine, & Edgerton, 1981; Coyle *et al.*, 1981; Kanehisa & Miyashita, 1983b; Moffroid & Whipple, 1970). The fact that only half of the dynamic training involved concentric activity may also have confounded the chances of finding a velocity-specific effect in the current study. While it is dynamic lifting and lowering that is the widely practised form of resistance training, a comparison of purely concentric and isometric work would provide a more interesting neurophysiological comparison.

Isokinetic strength gains were significantly greater at 0.79 $\text{rad} \cdot \text{s}^{-1}$ than at 5.24 $\text{rad} \cdot \text{s}^{-1}$, irrespective of the type of training. The training velocities for both types of training (isometric, 0; dynamic, 1.57 $\text{rad} \cdot \text{s}^{-1}$) were closest to the slowest isokinetic test velocity of 0.79 $\text{rad} \cdot \text{s}^{-1}$, and most distinct from the fastest test velocity of 5.24 $\text{rad} \cdot \text{s}^{-1}$. This provides further evidence for a velocity specificity effect.

In conclusion, training isometrically at four angles produced significantly greater gains in isometric strength across a range of angles (assessed with two dynamometers), but similar gains in isokinetic (dynamic) strength in comparison to dynamic training. The greater isometric strength gains could be due to a residual angle specificity effect or, perhaps more likely, the greater absolute torque involved with isometric training.

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