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Effects of low-load resistance training combined with blood flow restriction or hypoxia on muscle function and performance in netball athletes

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ABSTRACT

Objectives: To investigate the effect of blood flow restriction or normobaric hypoxic exposure combined with low-load resistant exercise (LRE), on muscular strength and endurance.
Design: A randomised controlled trial.
Methods: Well-trained netball players ($n = 30$) took part in a 5 weeks training of knee flexor and extensor muscles in which LRE (20% of one repetition maximum) was combined with (1) an occlusion pressure of approximately 230 mmHg around the upper thigh (KT, $n = 10$), (2) hypoxic air to generate blood oxy-haemoglobin levels of approximately 80% (HT, $n = 10$) or (3) with no additional stimulus (CT, $n = 10$). The training was of the same intensity and amount in all groups. One to five days before and after training, participants performed a series of strength and endurance tests of the lower limbs (3-s maximal voluntary contraction [MVC_3], area under 30-s force curve [MVC_{30}], number of repetitions at 20% 1RM [Reps201RM]). In addition, the cross-sectional area (CSA) of the quadriceps and hamstrings were measured.
Results: Relative to CT, KT and HT increased MVC_3 (11.0 ± 11.9% and 15.0 ± 13.1%), MVC_{30} (10.2 ± 9.0% and 18.3 ± 17.4%) and Reps201RM (28.9 ± 23.7% and 23.3 ± 24.0%, mean ± 90% confidence interval) after training. CSA increased by 6.6 ± 4.5%, 6.1 ± 5.1% and 2.9 ± 2.7% in the KT, HT and CT groups respectively.
Conclusions: LRE in conjunction with KT or HT can provide substantial improvements in muscle strength and endurance and may be useful alternatives to traditional training practices.

1. Introduction

Strength training is an important part of most sports conditioning programmes and plays a major role in injury prevention and rehabilitation.[1] It is suggested that resistance of at least 60% of one repetition maximum (1RM) is required to produce strength gains, however, for optimal strength gain, loads in excess 80% of 1RM are usually recommended.[2] Low-load resistance exercise (20–50% of 1RM), combined with blood flow restriction, has been proposed as an alternative to heavy resistance exercise, especially when high forces acting upon the musculo-skeletal system are contraindicated.[3] Several studies using low to moderate resistant exercise combined with blood flow restriction have shown muscle strength (approximately 8–14%) and size (approximately 4–12%) improvement.[4,5] However, the physiological mechanisms by which blood flow restriction combined with low-load resistance exercise increases muscle strength and size are not clear.

Intermittent hypoxic training (IHT), where the amount of oxygen presented to the muscle is reduced discontinuously, has been reported to improve aerobic,[6] and anaerobic[7] performance in athletes. Others have found substantial improvement in elbow extensor and flexor muscle strength in untrained male participants after IHT,[8] while improved 30-s all out power in a Wingate test after IHT has also been reported.[9] Since blood flow restriction (also known as Kaatsu training) produces a hypoxic muscular environment resulting in adaptation and subsequent muscle hypertrophy[10] we hypothesised that similar muscular hypertrophy and subsequent muscular strength improvement could be achieved by exercising in hypoxia alone (without the need for blood flow restriction).

Therefore this study will investigate whether any change in muscle cross-sectional area and strength occurring with low-intensity resistive exercise during blood flow restriction can be

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replicated with IHT. In addition, as the majority of the research in this area has been conducted on males, this study aimed to investigate the physiological changes of such exercise in young female athletes. Finally, we investigate whether any improvement in strength and endurance from the interventions results in any beneficial changes in sport specific performance.

2. Methods

Thirty female netballers (age 20.2 ± 3.3 years, height 168.4 ± 5.8 cm; body mass 65.2 ± 6.5 kg, mean ± SD), gave their written informed consent to participate in the study that was approved by the Lincoln University Human Ethics Committee. All participants were in training, similarly matched in netball ability, had equal training volume, and were trained by the same physical conditioner. Participants refrained from consuming caffeine or alcohol or performing strenuous exercise for 24 h prior to testing.

All participants performed bilateral knee extensions and flexions from 0° to 90° in a seated position for extension and prone position for flexion using an isotonic leg extension (FitnessWorks W105, Auckland, New Zealand) and flexion (FitnessWorks W104, Auckland, New Zealand) machine. During rest and while performing each set of knee extensions and flexions, participants in the HT group received normobaric hypoxic gas from a face mask via a hypoxicator system (Airo HTMH; High Tech Mixing Head, Airo Limited, New Zealand). The fraction of inspired oxygen concentration (F_IO_2) was automatically adjusted by the hypoxicator using a biofeedback control system to maintain arterial oxygen saturation (SpO_2) at ~80% (normal SpO_2, approximately 99%). The KT group performed training with blood flow restriction (Kaatsu training, KAATSUMASTER® mini, Sato Sports Plaza Inc., Japan) in both thighs. During training, the pressures exerted by the Kaatsu cuffs (which were approximately 5 cm in width), was gradually increased by 10 mmHg each day, starting from 160 mmHg at Day 1 going up to 230 mmHg at Day 8. The pressure then remained unchanged throughout the training session.[5] Heart rate and arterial oxygen saturation were monitored by a pulse oximeter at the end of each exercise set (Sport-Stat, Nonin Medical, Minneapolis, MN). The CT group performed knee extension and flexion exercises with the Kaatsu cuffs on but not inflated (<5 mmHg) and breathed normal ambient room air.

Participants completed three training sessions per week for 5 weeks. Each training session consisted of three sets of knee extensions followed by three sets of knee flexions to failure (total of 6 sets) with a 30 s rest between sets and a 2 min rest between exercises. Approximate reps per set were 28 ± 2, 24 ± 2, 22 ± 2, (mean ± SD) for extension and 36 ± 3, 31 ± 3, 26 ± 3 for flexion. The weight was raised and lowered at similar rates taking approximately 1 s for concentric and 1 s for eccentric movement. The resistance used was 20% 1RM, which was determined at least two days before the start of training and was unchanged throughout the study. The HT and CT groups were then instructed to match the repetitions performed by the KT group to ensure equal training load between groups. Participants were asked to breathe the gas mixture or keep the thigh blood flow occluded throughout the training session (approximately 12–13 min).

After familiarisation 1–2 days prior, all muscle contractile measurements were conducted on the non-dominant leg with the subjects seated in a leg extension machine. Force was measured by a load cell (10 Hz, Tension/S-beam load cell, AST 500, PT Instruments, UK) fixed to the lower leg with a Velcro strap around the ankle (2–3 cm above the medial Malleolus) at a knee angle of 80°. Maximal voluntary contraction (MVC) measurements consisted of producing the highest possible force for three seconds (MVC_3). The subjects were strongly encouraged and the best force from two trials (interspersed by a five minute recovery) was used for analysis. After a 10 min rest, muscle strength-endurance was measured by having the subjects perform a 30-s MVC (MVC_{30}). Area under the 30-s curve was used as measure of strength-endurance. Fatigue was calculated as the decrease in force from the maximum to the minimum over the 30 s timeframe. After a further 10 min rest, dynamic muscle endurance was measured by calculating the number of repetitions participants could complete at a constant cadence (1 s concentric and 1 s for eccentric movement) with a 20%1RM load (Reps201RM). All isometric strength values were standardised to account for any changes in body weight.

Two days before and after the 5-week training period all athletes completed a series of sport-specific fitness tests for netball players including explosive power, sprinting, agility and a maximal multistage 20-m shuttle run test [20-MST]. The athletes were familiar with these tests which were a regular part of their testing routine. Explosive power was evaluated by the maximum effort countermovement jump test using standard procedures (Yardstick, Swift Performance Equipment, New South Wales), while explosive speed was measured by 5 and 10 m sprints. The agility 505 test is designed to test agility by minimising the influence of individual differences in running speed while measuring acceleration before and after change of direction. Times for all running tests were recorded using two sets of electronic speed timing lights (Speed-Light, Swift Performance equipment, Goonellabah, Australia). We used standard procedures for testing aerobic fitness via the 20-MST.[11] The maximal oxygen consumption ($\dot{V}O_{2max}$) and maximal attained speed (MAS) were predicted based on 20-MST data.[12] All tests were performed at the same time of day under similar temperature conditions on a non-slip surface in a covered stadium.

A magnetic resonance imaging (MRI) scan was conducted on participants 1 week before and 2–5 days after the 5-week training period. Images were acquired on a Siemens 1.5 T Avanto MRI. Coronal STIR (short-tau inversion recovery) images were acquired through the thighs bilaterally using a large field of view. From the axial images, at the level of the mid-thigh, cross sectional areas of knee flexor and extensor muscles were obtained using the InteleRad PACS viewing software. The area to be measured was outlined by hand, and the PACS software calculated the cross sectional area of the desired outlined area. Each measurement of cross sectional area was obtained by a blinded observer 3 times, and the means of all three were used.

A visual analogue scale was used for determining knee flexor and extensor muscles pain. The scale has been established as a valid and reliable instrument to measure muscular pain intensity.[13] The participants were asked to record their daily subjective rating of pain after resistance training on a 10-point scale (0 no pain, 10 severe pain).

We used a specifically designed spreadsheet available for controlled trials to calculate magnitude-based inferences about effect sizes,[14] and then to make assumptions about true (population) values of the effect, the uncertainty in the effect was expressed as 90% confidence limits (CL). The probability that the true value of the effect was practically negative, trivial, or positive accounted for the observed difference, and typical error of measurement.[15] The natural logarithm of each measure was analysed to reduce any effects from non-uniformity errors and then back-transformed. We generated the smallest worthwhile change value by multiplying the baseline between-subject standard deviation by Cohen's value of the smallest worthwhile effect of 0.2.[16] The chances that the true effects were substantial were estimated by the spreadsheet[14] when a value for the smallest worthwhile effect was entered. We used of 1% for the sport specific performance measures (jump, sprint, etc.). Effects that were simultaneously both >75% likely positive and <5% negative were considered substantial and beneficial. An effect was deemed unclear if its confidence interval overlapped

Table 1
Changes in muscular performance from baseline in the three groups as a result of 5 weeks training.

	CT	KT	HT
MVC3 (%)	1.0 ± 14.3	12.1 ± 7.8	14.9 ± 10.7[a]
MVC30 (%)	0.4 ± 7.0	11.4 ± 10.1[a]	16.9 ± 17.9[a]
Reps201RM (%)	86.4 ± 15.7	140.0 ± 33.5[a]	129.2 ± 37.1[a]

Data are percentage means ± SD. MVC3, the peak maximum voluntary contraction in 3 s; MVC30, area under the 30 s MVC curve; Reps201RM, the number of repetitions able to be performed at 20% 1RM; CT, control training; KT, Kaatsu training; HT, hypoxic training.

[a] Substantial difference from CT.

the thresholds for substantiveness; that is, if the effect could be substantially positive and negative.

3. Results

Change in the performance variables (MVC$_3$, MVC$_{30}$, and Reps201RM) as a consequence of the 5 weeks training are given in Table 1. Clearly, substantial improvements in all performance measures were found after training in the hypoxic training groups. While training with blood flow restriction showed worthwhile gains in MVC$_{30}$ and Reps201RM, the control group's performance remained relatively unchanged. Differences between KT and HT groups for MVC$_3$, MVC$_{30}$ and Reps201RM were trivial or unclear (Table 2). Relative to control training, 5 m and 10 m sprint, 505 agility, vertical jump, 20-MST, MAS, and predicted $\dot{V}O_{2max}$ performance were substantially increased in the KT group. Interestingly, KT showed higher benefit than hypoxic training in the 505 agility run (Table 2).

As a result of training we found the combined CSA of the extensor and flexor muscles (excluding adductors) increased by 6.6 ± 4.5%, 6.1 ± 5.1% and 2.9 ± 2.7% in the KT, HT and CT groups respectively. The individual CSA of the extensors increased by 5.7 ± 4.0%, 2.8 ± 1.8% and 2.4 ± 1.7% in the KT, HT and CT groups and flexor muscles increased by 7.7 ± 5.0%, 10.0 ± 5.0% and 3.4 ± 3.4% in the KT, HT and CT groups respectively. Compared to the CT group, the combined extensor and flexor CSA increased substantially in the KT (7.6 ± 5.8) and HT group (5.3 ± 3.0, mean ± 90% CL). Changes in extensor muscle cross-sectional area were greater in KT compared to HT (3.2 ± 2.1 vs. 1.8 ± 1.2 cm^2), whereas cross-sectional area increase was larger for HT compared to KT for flexor muscles (1.7 ± 0.8 vs. 1.1 ± 0.8 cm^2) (Fig. 1).

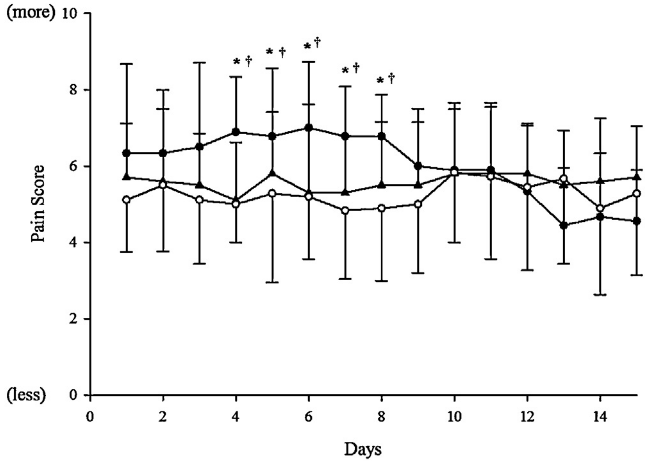

Fig. 1. Daily pain score in the three groups. Compared to the CT or KT groups, pain was higher in the HT group throughout the first 9 days of training, particularly from Days 4 to 8.

4. Discussion

The major finding of this study was that 5 weeks of low-load resistance exercise in conjunction with either blood flow restriction or hypoxia increased muscle strength and endurance compared to control training (without blood flow restriction and hypoxic breathing). However, while both types of training improved muscle strength and endurance, Kaatsu training appeared to provide the most beneficial sport specific performance changes for netball players.

This is the first study to compare the effects of LRE coupled with blood flow restriction or IHT on muscle strength, endurance and performance on a similar cohort of female subjects. Studies have consistently shown that Kaatsu training induces increased muscle strength and hypertrophy[4,5,17] but relatively little is known about the effects of LRE with hypoxia. Friedmann et al.[18] found that LRE (6 sets of 25 reps at 30%1RM, 3 times per week for 4 weeks) combined with hypoxia ($F_IO_2 = 0.12$) had little effect on strength endurance, maximal strength or CSA compared to identical exercise completed under normoxic conditions. However, more recently Nishimura et al.[8] reported substantial increases in CSA of the elbow flexors and extensors in the hypoxic compared to normoxic group after 6 weeks of resistance training (4 sets of 10 reps at 70%1RM, 2 times per week, $F_IO_2 = 0.16$). Differences in the effects found between studies may be due to methodological differences including the hypoxic exposure dosage. Both the current study and that of Nishimura et al.[8] required participants to breathe hypoxic gas during training and recovery, whereas participants in the Friedmann et al.[18] study only breathed hypoxic gas during the resistance exercise period (reverting to ambient room air between sets). Additionally, Nishimura et al.[8] and the current study trained participants for 6 and 5 weeks respectively whereas participants in the Friedmann study trained for only 4 weeks. As suggested by Bonetti and Hopkins[19] hypoxic dosage (days of exposure or daily exposure hours) is a major factor in subsequent adaptation and performance change with simulated altitude training and may explain the discrepancy between the results of Friedmann et al.[18] and the current study.

The blood occlusion and hypoxic groups showed almost identical improvement in both strength and endurance. We found the strength gains (likely beneficial in MVC$_3$), concurrent with total muscle CSA, increased in both KT (6.6 ± 4.5%), and HT (6.1 ± 5.1%), which were substantially higher compared to the control training (2.9 ± 2.7%). Comparable findings have been reported recently where LRE with blood occlusion caused increases in isometric strength of 8% following 4 weeks of knee extension exercises.[17] The isokinetic torque at all velocities and dynamic knee extension endurance were also increased in LRE athletes compared with control training.[4] In the present study, we found extensor muscles increased from baseline by 5.7 ± 4.0% in the KT. The recent study by Norrbrand et al.[20] reported that using resistance training by weight stack device (for concentric resistance training) and flywheel machine (for concentric–eccentric resistance training) without blood flow restriction show the difference CSA improvement. The study found that after resistance training muscle cross-sectional area improvement only 3.0% and MVC less improvement compared to their concentric–eccentric training program. Seynnes et al.[21] also found that even high resistance exercise increased quadriceps femoris CSA by 3.5%. This indicates that our protocol low-load resistance training (concentric resistance training 20% 1RM) combined with blood flow restriction effectively to increase CSA compared to these recent studies.

Mechanisms behind the changes witnessed in the current study probably involve the effect of low oxygen concentration on muscle function. According to Henneman's Size principle' motor units are normally recruited in order of smallest to largest as the

Table 2
Mean changes in performance of the 3 groups and the chances that the true difference represents a substantial improvement or impairment in strength and sport-specific fitness performance.

	Change in performance (%)			Chance that the true difference is substantial	
			Difference ± 90 CL	%	Qualitative
KT vs. CT group					
	KT	CT			
MVC3	12.1 ± 7.8	1.0 ± 14.3	11.0 ± 11.9	80	Likely
MVC_{30}	11.4 ± 10.1	0.4 ± 7.0	10.2 ± 9.0	85	Likely
Reps201RM	140.0 ± 33.5	86.4 ± 15.7	28.9 ± 23.7	91	Likely
Vertical jump	7.3 ± 10.6	2.4 ± 6.0	4.8 ± 10.0	76	Unclear
5 m sprint[a]	−13.2 ± 3.9	3.7 ± 8.9	−16.3 ± 14.4	97	Very Likely
10 m sprint[a]	−12.0 ± 4.8	−9.1 ± 5.6	−3.3 ± 5.2	79	Unclear
505 agility[a]	−10.5 ± 8.5	−1.6 ± 1.5	−9.0 ± 6.7	98	Very Likely
20-MST	19.9 ± 4.9	7.4 ± 8.8	11.7 ± 7.4	98	Very Likely
MAS	5.6 ± 1.7	2.3 ± 2.3	3.3 ± 2.0	96	Very Likely
$\dot{V}O_{2max}$	10.0 ± 3.6	4.2 ± 4.6	5.1 ± 3.9	96	Very Likely
HT vs. CT group					
	HT	CT			
MVC_3	14.9 ± 10.7	1.0 ± 14.3	15.0 ± 13.1	86	Likely
MVC_{30}	16.9 ± 17.9	0.4 ± 7.0	18.3 ± 17.4	89	Likely
Reps201RM	129.2 ± 37.1	86.4 ± 15.7	23.3 ± 24.0	88	Likely
Vertical jump	7.5 ± 7.6	2.4 ± 6.0	5.0 ± 6.4	86	Unclear
5 m sprint[a]	−4.4 ± 7.3	3.7 ± 8.9	−4.3 ± 9.7	73	Unclear
10 m sprint[a]	−4.1 ± 5.6	−6.5 ± 4.2	2.6 ± 4.7	73	Unclear
505 agility[a]	−2.2 ± 2.0	−0.8 ± 1.5	−1.5 ± 1.6	75	Likely
20-MST	13.7 ± 9.6	7.4 ± 8.8	4.1 ± 8.3	74	Unclear
MAS	4.7 ± 2.7	2.3 ± 2.3	1.9 ± 2.3	74	Possibly
$\dot{V}O_{2max}$	8.6 ± 5.0	4.2 ± 4.6	3.5 ± 4.5	83	Likely
KT vs. HT group					
	KT	HT			
MVC_3	12.1 ± 7.8	14.9 ± 10.7	−4.2 ± 9.4	43	Trivial
MVC_{30}	11.4 ± 10.1	16.9 ± 17.9	−4.7 ± 15.9	53	Unclear
Reps201RM	140.0 ± 33.5	129.2 ± 37.1	5.1 ± 29.8	41	Unclear
Vertical jump	7.3 ± 10.6	7.5 ± 7.6	0.5 ± 10.2	46	Unclear
5 m sprint[a]	−13.2 ± 3.9	−4.4 ± 7.3	−7.2 ± 11.3	86	Unclear
10 m sprint[a]	−11.0 ± 4.8	−10.2 ± 5.6	−0.9 ± 6.0	49	Unclear
505 agility[a]	−10.5 ± 8.5	−2.2 ± 2.0	−7.6 ± 7.0	95	Very Likely
20-MST	19.9 ± 4.9	13.7 ± 9.6	5.5 ± 7.3	85	Unclear
MAS	5.6 ± 1.7	4.7 ± 2.7	1.1 ± 2.2	54	Unclear
$\dot{V}O_{2max}$	10.0 ± 3.6	8.6 ± 5.0	0.9 ± 5.1	58	Unclear

±90% confidence limits; add and subtract this number to the mean effect to obtain the 90% confidence limits for the true difference. MVC3, the peak maximum voluntary contraction in 3 s; MVC30, area under the 30 s MVC curve; Reps201RM, the number of repetitions able to be performed at 20% 1RM; 20-MST, 20-m shuttle run test; MAS, maximal attained speed during the 20-m shuttle run test; $\dot{V}O_{2max}$, estimated maximal oxygen consumption from the 20-m shuttle run test; CT, control training; KT, Kaatsu training; HT, hypoxic training.

[a] Since the 5, 10 m sprint and 505 agility tests are all timed sprints a negative value represents a faster time or an improvement in performance. V.

contraction increases.[22] It is currently thought that in general, type I motor units are recruited first, then type II are recruited as the force required to be generated is increased. There is evidence that breathing hypoxic air during cycle ergometer training increases type II recruitment compared to normoxia.[23] Evidence also exists for a similar alteration to the motor unit recruitment pattern during resistance exercise with blood flow restriction.[24] We speculate that low-load resistance training with either blood flow restriction or hypoxia causes a reduction in the concentration of oxygen in the blood. It seems more likely that many type I fibres will fatigue with exercise in hypoxic/ischaemic conditions, thus forcing the recruitment of type II fibres as the training continues. The progressive increase in the recruitment of type II motor units increases the stress on these units and subsequently produces adaptation in the form of hypertrophy of these motor units.[25]

It is generally believed that muscle strength gains are related to muscle size increases.[4] Possible mechanisms behind the muscle size gains resulting from both blood flow restriction and IHT training may be due to satellite cell activation, growth hormone or anabolic agent release,[26] or perhaps reactive oxygen species (ROS: nitric oxide). Tanimoto et al.[10] reported that using Kaatsu can cause large changes in muscle oxygenation levels during and after exercise (lowered during exercise and elevated after exercise). This variation in oxygen levels may cause an increased production of reactive oxygen species like nitric oxide, thereby stimulating muscle growth by activating muscle satellite cells.[27] Kon et al.[28] reported that the increased muscle metabolites due to the occluded blood supply resulted in increases in growth hormone after resistance exercise in hypoxia compared to normoxia. We suggest that whatever the mechanism, the availability of oxygen is a major factor in both blood flow restriction and hypoxic training with LRE.

CSA increased in all groups as a result of training, however, KT and HT showed marked improvement compared to CT. Interestingly, with similar intensity and work load, KT produced more hypertrophy in the knee extensors than flexors while HT tended to increase knee flexor hypertrophy. A possible reason for these differences is pressure differences between the extensors and flexors during training. Perhaps vessels were not properly occluded during knee flexion training on the leg curl compared to a seated position on the knee extension machine, resulting in less stress being applied to the flexor muscles in KT. Other studies have reported that extensors tend to benefit more, both in strength and size gain. Abe et al.[5] found that muscle size of the mid-thigh increased 5.3% after 3 weeks of walk training and blood flow restriction in both flexors and extensors but isometric strength improved only in knee extensors.

An unexpected finding in the present study was the sport-specific fitness improvement in KT participants compared to the

HT group. It is unclear why these differences were observed. We hypothesised that both groups would obtain similar benefits from the training regimens which were substantiated to some degree by the similarity in hypertrophy between the two groups. It may be that Kaatsu training does something different to the body compared to IHT. We speculate that the Kaatsu technique which occludes local blood vessels, subsequently lowers oxygen availability in the working muscles to a greater extent than in the hypoxic technique. Tanimoto et al.[10] reported that low-load resistance exercise (30% 1RM) with blood flow restriction produced the lowest muscle oxygenation during exercise (approximately 22% of baseline values) compared to more traditional resistance exercise without blood flow restriction (approximately 25%, 29% and 37% of baseline values for 50% 1RM isotonic long slow, 50% 1RM isometric and 80% 1RM isotonic fast exercise respectively). It has also been reported that exercise in acute and chronic hypoxia causes muscle blood flow to be attenuated[29] resulting in low oxygen transport within the muscle. Therefore, both Kaatsu and IHT probably cause hypoxic conditions in muscles, however, the actual reduction of oxygen or alternatively the subsequent stress and adaptation to hypoxia and resistance training may be different between the two training protocols. More research measuring oxygen saturation levels would be needed to confirm this hypothesis.

Both KT and HT groups showed substantial improvements in muscle endurance (MVC_{30}) compared to the CT group. While mechanisms for this change were not the focus of this inquiry, potential causes include neural,[24] metabolic,[30] or skeletal muscle changes as a result of training in a hypoxic intramuscular environments.

Another unexpected finding was the daily subjective pain score. We expected that the KT group would have a higher pain score than the other two groups due to the pressure from cuffs resulting in blood accumulation in the limbs. However, exercise training with blood flow restriction showed similar pain scores to the control group. Exercise training while breathing hypoxic gas seemed to be more noxious (higher pain scores) particularly in first half of the 15 day training period. Causes for this inconsistency in pain are unclear. Perhaps the muscle oxygen levels in the HT group may have been lower than in the KT group which may have resulted in more Type II muscle fibres being recruited during training, causing more stress to these muscles and more damage. However, if this were the case one would also expect a greater amount of force improvement in these muscles post intervention which was not evident. Mechanisms causing this pain difference between the two training regimes require further investigation.

This study has found that both blood flow restriction and hypoxic training in conjunction with low-load resistant exercise improved MVC_3, MVC_{30} and Reps201RM. In addition, both blood flow restriction and hypoxic training substantially increased muscle cross-sectional area compared to exercise training alone. These results suggest that low-load resistance training in combination with hypoxic training or blood flow restriction is very likely to be worthwhile for improving isometric strength and endurance which can also be transferred to improved sport-specific female netball fitness.

Practical implications

- Athletes and coaches may be able to utilise these exercise regimes for sports where high levels of muscle strength and endurance are required.
- The use low-loads (20% 1RM) combined with either blood flow restriction or intermittent hypoxia may be a useful training alternative to traditional high-load resistive training.
- The use of blood flow restriction and low-load resistive training can only be used for limb muscles, whereas similar training under systemic hypoxia is a useful alternative for all muscles of the body.

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