Effects of Blood Flow Restriction via KAATSU AQUA on Speed and Endurance in Young Water Polo Players

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ABSTRACT

Venous blood flow restriction is a relatively novel method of training which in the past showed remarkable results in regards to muscle hypertrophy and strength gains. Vast majority of previous publications focused mainly on dry-land exercise and sports. The objective of this study was to examine effects of KAATSU AQUA on swimming speed and high intensity exercise endurance (HIEE) in swimmers and water polo players. Sixteen young, well trained, male water polo players, divided into two groups (experiment and control) used the same training program for total of 11 practice sessions. High Intensity training was conducted for 11 sessions during the first 30 minutes of practice with arm blood flow restriction for approximately 15 minutes followed by blood flow restriction in the legs for approximately 15 minutes. Pre-training and post-training tests of 10 consecutive maximum intensity 50 yards sprints were conducted in order to examine improvements in speed, as demonstrated by average 1^{st} 50 yard time, improvement in HIEE, as shown by the average time for all 10 trials, and improvement in endurance after lactic acid accumulation as demonstrated by average time for last 5 trails only. The results reveal statistically significant ($p<0.05$) improvement for KAATSU AQUA group in all three categories, while the control group made no significant improvement in neither of the categories. It is concluded that KAATSU AQUA restricted blood flow causes improvement in swimming speed, high intensity exercise endurance, and endurance after lactic acid has already been accumulated in the muscles of young water polo players.

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INTRODUCTION

KAATSU is a training system that involves pressure belts applied to proximal portions of upper and lower limbs (Sato, 2008). It has been developed in Japan by Dr. Yoshiaki Sato over the course of 40 years. KAATSU literally means “training with additional pressure” (Sato, 2008). The goal of added pressure is to safely restrict the blood flow to the working muscles in the limbs which causes blood pooling in capillaries within the limb. With the pooling of blood in veins, the amount of blood that goes back to the heart is reduced and thus the arterial blood flow is also reduced (Sato, 2008). With the reduced amount of blood that flows to the muscles, the amount of oxygen and nutrients, especially glucose, is greatly reduced. This forces the muscles to adapt to low oxygen state. Studies show that hypoxic conditions created by the occlusion increase the release of growth hormone, norepinephrine, IFG-1(Abe et al., 2005a) and other hormones related to muscle hypertrophy and increase in strength (Takano et al., 2005). These hormones are significant factors for hypertrophy and strength adaptations. It is uniformly accepted (Baechle & Earle, 2000; American College of Sports Medicine 2002) that approximately 65% or greater resistance is required to stimulate strength gains and muscle hypertrophy. Application of KAATSU bands that restrict the blood flow show that even low-intensity exercise of 20% of one repetition maximum combined with vascular restriction can cause increase in muscle size (Karabulut , Abe, Sato & Bemen, 2007).

When exploring the application KAATSU AQUA and its effect on increase in speed and endurance, it is hypothesized that three basic adaptations play the most important role (Karabulut et al., 2007). Among other physiological adaptations, previous studies have shown significant changes in following compared to training without venous blood flow restriction:

1) Fast twitch fiber muscle recruitment (Takarada, Tsuruta, & Ishii, 2004; Moritani et al., 1992)

2) Metabolite Accumulation (Tanimoto, Madarame &Ishii, 2005)

3) Strength increase and Hypertrophy (Abe et al., 2005; Shinohara et al., 1998)

Muscle Fiber Type II Recruitment

KAATSU is hypothesized to affect the three types of muscle fibers in the human body. Type I, commonly called slow twitch fibers, type II a and II b which are both referred to as fast twitch muscle fibers. Slow twitch fibers use a lot of oxygen and are slow fatiguing. During exercise or stress in general these oxygen consuming fibers are activated first. Only under high intensities and reduced amount of oxygen do fast twitch fibers start to activate (McArdle, Katch F. & Katch V., 1996). Type II fibers have a high threshold of activation, so a large force or high speed of muscle contraction is required to activate them. However, oxygen supply also affects the recruitment of fast twitch muscle fibers (Tipton, 2006). One important adaptation of KAATSU training is an early activation of fast twitch fibers (Moritani, Sherman, Shibata, Matsumoto & Shinohara, 1992). EMG (electromyography) studies confirm that there is an increase in motor neuron firing and motor unit recruitment with blood flow restriction (Takarada, Tsuruta, & Ishii, 2004). In addition, Moritani and others have demonstrated that even 20% of one repetition maximum with blood flow restriction is enough to significantly increase motor unit activation (Moritani et al., 1992). Since the amount of oxygen that is flowing to the muscles is greatly reduced while using the KAATSU AQUA bands compared to the regular training, slow twitch fibers cannot sustain the stress applied on the body, therefore fast twitch fibers have to be activated much sooner and to a lot greater extent (Kawada, 2005).

Metabolite Accumulation

Recruitment of fast twitch muscle fibers through oxygen supply reduction shifts the energy production from aerobic respiration toward anaerobic pathway of glycolysis. This way of producing energy causes a large lactic acid accumulation in the muscles (Anderson, Rhodes 1989). For athletes one of the most important adaptations to high levels of lactic acid is the improvement of body's buffering mechanism. This mechanism which contains sodium bicarbonate buffer helps to efficiently remove the acid from a working muscle and turn it into a non-acidic lactate (Bompa & Haff, 2009). Although, there are some controversies about whether the lactic acid is the primary cause of muscle fatigue, there is undoubtedly a strong correlation between the fatigue and level of lactate accumulated (Cairns, 2006). A presence of many H^+ ions will reduce the power output during the activity (Laursen & Jenkins, 2002). Therefore, training above lactate threshold, with the considerable amount of acid built up is highly beneficial for sports that require consecutive bouts of maximum intensity effort. In addition, Tanimoto and others have demonstrated that training with blood occlusion causes greater metabolite accumulation than even high intensity training (Tanimoto at el., 2005).

Increase in muscular strength and size

Many sports benefit from an increase in muscle strength and power. American College of Sports Medicine recommends that in order to produce an increase in muscular size and strength, at least 65 % of 1 repetition maximum should be used for strength training.(ACSM, 2002) This is generally attributed to an increased level of post-exercise anabolic hormone secretion such as human growth hormone, and IGF-1 and to Type II muscle fiber recruitment (Kraemer et at. 1990). A large number of studies have shown that high intensity exercise above the anaerobic threshold causes natural anabolic hormonal response. (Godfrey, Madgwick, & Gregory 2003; Kraemer et al. 1990). Hansen and colleagues (2001) have demonstrated that the elevated level of these hormones play a crucial role in all strength gains. However, a number of studies have shown that an increase in muscle hypertrophy and strength with blood flow restriction occurs at as low as 20 % of 1 repetition max. (Abe et al.,2005; Shinohara et al. 1998; Wernbom, Augustsson & Raastad. 2008). One publication has shown that exercise with KAATSU produces a 290 times greater GH concentrations compared to the baseline.(Takarada et al. 2000).

In one of the few blood restriction studies performed with swimmers, Fattah and Salem (2011) have demonstrated a significant increase in arm and thigh girth which corresponds to an increase in muscle size. The hypothesis is that because of all these adaptations to hypoxic conditions, the group that trains with KAATSU AQUA will show a greater improvement in speed and endurance.

Physiology of water polo

According to Smith (1998) in a game of water polo players are required to perform short bursts of maximal intensity work for the duration of approximately 15 seconds, followed by the lower intensity duration of <20 seconds. The three energy systems, aerobic, anaerobic lactic and anaerobic alactic (ATP and phosphocreatine) are all equally stressed. Heart rate during the water polo match is above 80 percent of VO_2 max, which suggests a high production of lactic acid and a need to remove it quickly. Most of the research on KAATSU training is based on increase in strength and size of the muscle (Karabulut et al. 2007). However, this is one of the first studies to examine the effects of blood occlusion during aquatic sports.

Purpose

The main purpose of this study was to test whether KAATSU AQUA can lead to significant improvement in performance in speed and high intensity exercise endurance. The hypothesis is that reducing the blood flow and thus oxygen and nutrient supply will force a positive adaptation to training.

METHODS

Participants:

Sixteen young healthy male water polo players aged 12-14 volunteered to participate in the study. All subjects were members of Huntington Beach Water Polo Club and have played water polo for minimum of two years. Written consent was obtained from all participants and their parents/guardians explaining the KAATSU AQUA training, goals and potential risks. Participants were told they are free to discontinue the experiment at any time.

Design:

In order to test water polo specific conditioning we employed the concept High Intensity Exercise Endurance (HIEE). HIEE refers to the ability to perform repeated bouts of close to maximal intensity work without complete recovery (Bompa & Haff, 2009). All sixteen participants performed a pre-test of 10 repetitive 50 yard maximum effort sprints on a minute and 15 seconds interval. That means that they would start the next repetition 1 minute and 15 seconds after the start of the previous one, regardless of the time it took them to complete the one before. The test was designed to give the athletes between 35 and 45 seconds rest between repetitions. This amount of rest is adequate enough only to replenish phospho-creatine and ATP stores in the muscle but not enough to remove the lactic acid accumulated during the sprints (Holmyard, 1994). Over the course of 10 trials of 50 yard sprint, the lactic acid will inevitably build up, muscle glycogen will start to deplete and the performance will decrease.

All participants were told not to pace themselves, but to swim every single of the 10 trails maximum intensity like it is the only one. After the pre-test subjects were randomly assigned to either experiment group, that was training with KAATSU AQUA bands (K Group n=8), or control group that was training without the bands (S Group n=8). All training and testing was performed in a 25 yard long pool. Both pre-test and post-test were conducted without the blood flow restriction for both groups. On the first day of training the pressure was set to 80 mm Hg for the arm bands and 100 mm Hg for leg bands using KAATSU AQUA mini sensor. The reason the pressure was initially set fairly low is to allow the players to get comfortable with bands.

Safety

According to the National Survey in Japan KAATSU is a safe training method. Based on the sample of 12,642 people 0.055% had superficial blood clot (venous thrombus) problems, pulmonary embolism 0.008%, and 0.008% had problems with damaged skeletal tissue (rhabdomyolysis) (Nakajima 2006). It is possible for the occlusion of blood vessels to cause microvascular occlusion. This is referred to as a no-reflow phenomenon (Kawada, 2005). We were constantly checking for this by examining limb coloration after a light pressure has been applied to it.

Training:

First three training sessions were performed with the initial pressure of 80 mm Hg and 100 mm Hg for arms and legs, respectively. By week two, the pressure was increased to 120 mm Hg for arms and 140 mm Hg for legs. This pressure chosen was based on the optimal results from many previous studies (Manini & Clark 2009; Karabulut et al., 2007). Almost all of the previous research was focused on land based exercises, so this is one of the first studies that examined the effect of blood restriction on aquatic sports. It is important to note that these pressures were set with muscles relaxed - without any contraction. During the exercise muscles contract and shorten, so the pressure set does not stay constant. When a muscle shortens, the pressure naturally increases; when it relaxes the pressure goes back to the initially set number.

All training sessions were performed during the first 30-40 minutes of a two hour practice. On average K group used arm bands for 15 minutes followed by leg bands for 15 minutes. Majority of the training consisted of high intensity intervals. Interval training refers to repeated short distance swims at high or maximum intensity. This type of training is best suited for improving lactate threshold and high intensity exercise endurance (HIEE), making it the preferred training method for sports like water polo, hockey etc, (McArdle et at., 1996).

Table 1 bellow shows the summery of training for both groups while K group had the bands applied. The summery shows the total distance swam per practice and the pressure applied for K group. During most practices, both arm and leg bands were used. For the purposes of this research the subjects never had both arm and leg bands applied at the same time.

Table 1. Pressure set and Total yards swam during training

Pressure mm HG (arms/legs) during training sessions 4 – 11	120 mm Hg arms 140 mm Hg legs
Total yards while wearing arm bands per session	200 - 400 easy 300 - 500 high intensity intervals with pulling only mixed in
Total yards while wearing leg bands per session	300- 500 high intensity intervals with kicking only mixed in
Total yards swam during the time bands were applied	500 - 1200

Table 2. Example of high intensity interval training sessions.

	Arm belts	Leg belts	Total Yards:
Day 4	200 yards easy 4 x 50 yards 85% intensity 4 x 50 yards – 1st lap pulling only, 2nd lap sprint	4 x 25yrd sprint 4 x 50 – 1st lap kick, 2nd lap sprint 4 x 50 – 1st kick, 2nd sprint	1100
Day 11	200 yard easy mixed 4 strokes 4 x 75 (1 lap pull, 2 sprint) on 1:30 4 x 25 sprint on 0:30 pace	4 x 75 (1 kick, 2 laps sprint) on 1:30 4 x 25 sprint on 0:30 pace	1200

Table 2 shows the examples of high intensity interval training. Most training days included swim sets similar to these, which were designed to replicate the intensities occurring during the water polo game. (Geladas & Platanou 2000).

All training sessions were performed during the first 30 – 40 minutes of regular two hour practice, three times per week. Both groups were performing the same training. After approximately 400 yards of warm-up majority of the training consisted of high intensity swims broken into several sets. Both groups received the same instructions. The only difference was that during training the K group was not able to swim as fast as the S group, because their muscles received less oxygen.

Data Analysis

Data was expressed as a mean value of the entire group for three different analyses. For the first analysis all ten trials were averaged, for the second analysis only the last five trials were counted, and for the final analysis only the value of the first trial was taken into account. Comparison between the pre test and post test as well as the comparison between the K and S groups was made using t-test. Differences were considered significant if $p < 0.05$.

RESULTS

Effects of KAATSU AQUA training on HIEE

As previously mentioned, HIEE relates to the ability to perform repeated bouts of maximal intensity exertions without complete rest. A way to measure HIEE is to look at the average time for all trials. Results show a significant improvement in post test compared to the pre-test for K group ($p=0.0036$) and no significant difference in post test compared to the pre-test for S group ($p=0.395$). In terms of seconds and percent improvement the experiment group got on average 1.59 seconds faster which corresponds to 4.67% improvement, while the control got

0.12 seconds faster or 0.36%. It is important to mention that the averages in pre-tests between the two groups were statistically not significant (p=0.4345). Analysis of the post-test data, however show that the two groups are significantly different from each other after the training was completed t_{dt14}=3.46, p=0.0038. Results are shown in Table 3.

Table 3. Average results for All 10 Trials

Group			Group		
Experiment (K)	Pre-Test Average	POST TEST Average	**Control (S)**	Pre-Test Average	POST TEST Average
K1	33.2	31.737	S1	33.19	33.06
K2	32.05	32.03	S2	32.62	35.08
K3	38.33	34.186	S3	38.2	37.21
K4	33.11	32.103	S4	34.75	33.512
K5	32.11	30.982	S5	32.02	31.52
K6	33.83	32.25	S6	32.13	32.87
K7	34.84	33.628	S7	35.55	34.26
K8	34.27	32.131	S8	32.74	32.71
Average	33.968	32.381	Average	33.9	33.778
Standard Deviation	2.0126	1.0327	Standard Deviation	2.141	1.7467
Difference(Pre-Post)	1.5866		Difference(Pre-Post)	0.122	
Percent Improvement	4.671		Percent Improvement	0.36	
Probability K group (Pre and Post)	0.0036		Probability S group (Pre and Post)	0.395	
Probability (Pre Tests between K and S)	0.4345		t Score (Pre Tests between K and S)- t_{df14}	0.805	
Probability (Post Tests)	0.0038		t Score(Post Tests)-t_{df14}	3.460	

Effects of KAATSU AQUA training on lactate tolerance

By looking at the average for the last 5 trials only we can judge the improvement in endurance and lactate tolerance after lactic acid has already been accumulated in the muscles. In Table 4 one can see a statistically significant, 1.87 second average improvement for K group (p=0.0045), and only 0.45 second improvement for the group without the bands(S group), which is not statistically significant (p=0.1413). This represents a 5.37% improvement for the K group.

Before the training began there was no difference between the groups for the average speed in last 5 trials (p=0.338). Just like the analysis of all ten trials, the comparison of post tests shows a significant difference (t_{df14}=2.709; p=0.017), indicating that the K group had a much greater improvement.

Table 4. Average results for last 5 trials only

Group			Group		
	Pre-Test	POST TEST		Pre-Test	POST TEST
Experiment (K)	Average	Average	**Control (S)**	Average	Average
K1	34.62	32.732	S1	33.58	33.326
K2	32.72	32.22	S2	33.88	35.12
K3	39.84	34.694	S3	39.34	37.7
K4	33.54	32.764	S4	35.82	34.5
K5	32.9	31.596	S5	32.08	31.46
K6	34.22	32.82	S6	32.24	32.96
K7	35.36	34.064	S7	36.68	34.882
K8	35.58	32.92	S8	33.08	33.12
Average	34.848	32.976	Average	34.5875	34.1335
Standard Deviation	2.274	0.9814	Standard Deviation	2.509	1.874
Difference(Pre-Post)	1.87125		Difference(Pre-Post)	0.454	
Percent Improvement	5.3698		Percent Improvement	1.312	
Probability K group (Pre and Post)	0.00448		Probability S group (Pre and Post)	0.1413	
Probability (Pre Tests between K and S)	0.338		t Score (Pre Tests between K and S - t_{df14}	0.992	
Probability (Post Tests)	0.017		t Score(Post Tests)-t_{df14}	2.709	

Effects of KAATSU AQUA on speed

Participants were told to swim every one of the 10 trails maximum intensity, and not to try to pace themselves or save energy for the later trials. By examining the first trial only as shown in Table 5, we can evaluate subjects' speed and examine the effect of KAATSU AQUA training on its increase. After 11 training sessions the K group got on average 1.25 seconds faster, while the S group did not show any improvement. The difference between pre and post tests for K group showed significance level of t_{df14}=3.285, p=0.028.

Table 5. Results for the 1st Trial

Group			Group		
Experiment (K)	Pre-Test 1st Trial	POST TEST 1st Trial	**Control (S)**	Pre-Test 1st Trial	POST TEST 1st Trial
K1	30.1	29.38	S1	31.6	32.2
K2	30.2	30.2	S2	30.1	34.8
K3	35.6	31.02	S3	34.3	34.4
K4	31.7	29.53	S4	33	31.1
K5	28.9	28.86	S5	31.8	30.1
K6	32	31.1	S6	32.3	31.7
K7	33.7	32.2	S7	33	31.9
K8	30.3	30.2	S8	31.7	31.7
Average	31.5625	30.31125	Average	32.225	32.2375
Standard Deviation	2.196	1.089	Standard Deviation	1.246	1.595
Difference(Pre-Post)	1.251		Difference(Pre-Post)	-0.0125	
Percent Improvement	3.964		Percent Improvement	-0.0388	
Probability K group (Pre and Post)	0.028		Probability S group (Pre and Post)	0.4934	
Probability (Pre Tests between K and S)	0.1064		t Score (Pre Tests between K and S - t_{df14}	1.725	
Probability (Post Tests)	0.0054		t Score(Post Tests)-t_{df14}	3.285	

DISCUSSION

Dozens of previous publications have proven the efficacy of restricted blood flow on muscle hypertrophy and increase in strength (Takarata et al., 2004; Manini et al., 2009; Wernbom et al., 2008). Abe and others have shown that training with KAATSU improves sprinting speed in college aged male track athletes (Abe et al., 2005b). In the present study it was found that KAATSU AQUA bands, when applied properly, produce significant improvement in: 1) The ability to perform repeated bouts of close to maximum intensity exertions which mostly relate to water polo specific conditioning (Smith, 1998). 2) Improved lactic acid tolerance as demonstrated by looking at the improvement in average speed for the last five trials, when lactic acid in the muscles has already been accumulated. 3) Improvement in speed as demonstrated by examining the first 50 yard sprint.

All participants were highly trained for their age and conventional training does not readily improve performance. The group that trained with KAATSU AQUA showed improvement after only 11 training sessions. It is important to not that KAATSU AQUA can be applied both in the pre-season and during the competitive season. Training in the pre-season is used mainly for conditioning, so including KAATSU AQUA could allow for faster improvement and overall higher levels of conditioning compared to traditional training. During the competitive season, however athletes generally look to only maintain the gains accomplished in the pre-season. A program that heavily relies on conditioning during the competitive season might actually hinder the performance, because athletes will not have sufficient recovery time between sessions. However, training with KAATSU at low intensities produces the same physiological response, but with less muscle damage (Takarata et al., 2000). Less muscle damage generally means faster recovery time and lesser chance of overtraining. The results from this study demonstrate that KAATSU AQUA can be safely used during the season as an effective conditioning method with a decreased chance of overtraining.

Previous studies show that even at low intensities during KAATSU training, there is a large increase in fast-twitch muscle fiber recruitment, strength gains and hypertrophy (Yasuda et al., 2004). Although this experiment did not examine the correlation between the strength gains/ muscle fiber activation and improvement in swimming speed, that correlation seems highly possible. Previous publications (Fattah & Salem, 2011; Shinohara et al. 1998) showed that swimming and low-intensity training with blood occlusion lead to strength and size increase, making it a highly possible reason for a significant improvement in speed compared to the conventional training. Future studies can examine the effect swimming KAATSU AQUA on muscle hypertrophy, strength and body composition.

Like improvement in speed, training with KAATSU AQUA does improve the HIEE, especially when lactic acid has already been accumulated. Blood flow restriction causes the accumulation of lactic acid in the muscles (Tanimoto, 2005). When muscles are being forced to train under the acidic conditions, the result is an improvement in lactate threshold and body's buffering mechanisms (Bompa, Haff, 2009). According to Bompa (2009) improved buffering of lactic acid to lactate is most important factor affecting an athlete's ability to develop HIEE. In water polo, hokey, certain track and swim events, etc. the ability to perform with high levels of lactate accumulated is of paramount importance. Fattah and Salem (2011) have shown that swimming with blood flow restriction changes Lactate/Pyruvate ratio, which suggests an improvement in lactic acid buffering and anaerobic threshold compared to the traditional training. Although lactic acid was not tested, this is a likely reason for the demonstrated increase in HIEE and endurance.

CONCUSSION AND PRACTICAL APPLICATION

KAATSU AQUA occlusion training appears to be an effective short term training method that improves performance significantly more than traditional high intensity training. The group with blood flow restriction had an almost 4% increase in speed, 4.6 % increase in

High Intensity Exercise Endurance, and even bigger 5.36% increase in HIEE in the second half of the experiment. The control group did not make any statistically significant adaptations even though they received the same training. Possible explanations for these improvements are Type II muscle fiber recruitment, more efficient Lactic Acid Buffering System, and strength increase. This study and subsequent research that will follow has a potential to improve the way athletes train both in the pre-competition period during the season. God gave us an amazing body and the ability to explore and understand the way it functions. If we continue to explore and learn about ourselves, but at the same time remain humble and not try to use or alter our bodies in the way He did not intended us to, we can prosper as both athletes or teachers and as Christians.

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