Influence of the KAATSU Training on the Strength Endurance of the Muscles of the Lower Extremities in Qualified Football Players

Alexander Golubev[1], Alla Samsonova[2] and Leonid Tsipin[3]

1 Degree Candidate's name, Lesgaft National State University of Physical Culture, Sports and Health, St. Petersburg, Russia.

2 Doctor of Pedagogical Sciences, Professor, Lesgaft National State University of Physical Culture, Sports and Health, St. Petersburg, Russia.

3 Doctor of Pedagogical Sciences, Professor, Lesgaft National State University of Physical Culture, Sports and Health, St. Petersburg, Russia.

Abstract

The **purpose** of this study is to determine the influence of KAATSU Training in the development of strength endurance in qualified football players.

Methods. 18 qualified football players (mean age: 19), who were split into control and experimental groups, took part in the study. Athletes of both groups performed three exercises for the muscles of the lower extremities, which included barbell squats, seated leg extensions and lying leg curls to muscular failure. The experimental group performed strength exercises using KAATSU Training. The number of squats with a barbell with a weight of 40% of 1RM (one-repetition maximum) on the shoulders, acute pain levels and delayed onset muscle soreness (DOMS) were measured using the 10-point VAS scale.

Results. The influence of KAATSU Training on the strength endurance of the muscles quadriceps femoris (QF) was reliably proven. 26 days after the start of strength training using KAATSU Training, the number of repetitions of barbell squats was 38±3, which represented significantly higher results ($p<0.05$) compared to those shown by control group athletes (25±3). Change in DOMS clearly corresponded to muscle damage and subsequent regeneration.

Discussion. Significant changes in strength endurance occurred 7 days after the termination of KAATSU Training, which we associate with the accumulation of energy substances in muscle fibres and an improvement in their capillarisation.

Keywords: KAATSU Training, BFR, occlusion training, strength endurance.

1. Introduction

Strength endurance occupies an important place in the physical fitness system of qualified football players, as the latter's ability to maintain maximum efforts in motor actions throughout the entire playing run depends on the level of the development of such muscular endurance [1, 2]. Special studies have demonstrated the existence of a relationship between muscular endurance of football players and the realization of their physical capabilities in the game [3, 4].

Currently, a variety of resistance exercises performed using the repeated effort method, with multiple instances of overcoming non-limiting resistance until significant fatigue, or the muscular failure method are used for the development of muscular endurance in football players [4]. The main period of training for the development of muscular endurance in football players is considered as a preparatory period [5].

The advantage of the muscular failure method is that, with its help, football players become resistant to fatigue and gain the ability to exercise muscle tension when performing technical and tactical actions throughout the match. The relative disadvantage of the method is that it may have an adverse impact on intramuscular coordination, which supports the coordinated operation of a football player's skeletal muscles when performing specific motor actions (such as receiving and handling the ball).

In addition to traditional methods of the development of physical abilities, innovative methods have begun to be introduced into sports routines in recent years. One such method is KAATSU Training.

The KAATSU Training system was developed and patented in Japan by Dr Yoshiaki Sato in the 1960s. KAATSU Training consists in encircling the upper part of the limb with a pneumatic cuff connected to an electric pressure regulation and control system, partially limiting the blood flow to muscles involved [6]. In Europe, this technique is referred to as Occlusion Training or Blood Flow Restriction (BFR) and is generally accepted as a blood flow restriction training (BFRT). Y. Takarada et al. [7] identified an increase in local muscular endurance during knee extensions in a group of athletes performing exercises based on KAATSU Training compared to an identical training without using the system. Training was held twice a week for eight consecutive weeks. A. Kacin and K. Strazer [8] evaluated local muscle endurance in healthy men in an extension exercise based on KAATSU Training using the muscular failure method compared to a similar method without using KAATSU Training took place on a weekly basis over a four-week period. The underlying study showed that blood flow restriction significantly increased local muscle endurance/ K.A. Larkin et al. [9] evaluated the effect of KAATSU Training on increasing muscle endurance at two workouts per week for three consecutive weeks at a load of 40% of the maximum. They concluded that this technique has a greater impact on angiogenic factors, which may contribute to an increase in capillarisation, which, in their opinion, may contribute to an increase in local muscle endurance. It should be noted that local muscular endurance and strength muscular endurance are understood as close phenomena described through their ability to maintain optimal strength performance parameters of movement over extended periods of time.

In parallel with the development of the muscular system using KAATSU Training in combination with aerobic exercises, a significant improvement in the indicators of maximum oxygen consumption and maximum heart rate has been demonstrated. It was also shown that training with blood flow restriction enhances the body's adaptation to aerobic exercises and muscular endurance development exercises by increasing the content of muscle glycogen and improving parameters associated with maximum oxygen consumption [10].

In many publications, authors argue for the use of KAATSU Training to increase strength, local muscle endurance and hypertrophy of muscle fibres [11, 12]. The level of such physical abilities is enhanced by using KAATSU Training in team sports, such as rugby and American football [13, 14]. Despite the fact that the use of KAATSU Training is recommended in sports for the development of athletes' muscular system [15], references to its use in football are extremely rare. Thus, options for the improvement of football players' local muscular endurance through KAATSU Training remain poorly understood.

The purpose of this study is to determine the influence of KAATSU Training on the development of strength endurance in qualified football players

2. Methods

To study the influence of KAATSU Training on local muscular endurance in football players, a pedagogical experiment was conducted over a period of three weeks. The experiment was conducted from July till August of the year 2019, which corresponded to the preparatory period of training cycle of football players. We studied changes in the strength endurance of the QF as one of the busiest muscle groups of football players [16]. The criterion for the level of development of this physical ability was the number of barbell squats that an athlete could perform to muscular failure with a burden of 40% of the maximum. In addition, DOMS in thigh muscles was evaluated.

Subjects. The study involved two groups of qualified football players (nine athletes in each group) with at least six years of experience and no medical restrictions. The experimental and control groups were uniform in terms of their composition and were consisting of athletes who didn't differ in age and in total body size (Table 1). Before the start of the experiment, all subjects were acquainted with its program and gave their informed written consent to participate in it.

Table 1. Physical characteristics of subjects

Group	Age, years	Height, cm	Weight, kg
Experimental, n=9	18.5±0.4	177±1	71.8±2.1
Control, n=9	18.9±0.5	180±2	69.1±2.2
Significance of differences between groups	p>0.05	p>0.05	p>0.05

Values are MEANS±SE

Experimental procedure. In the weekly microcycle of the football team that included the members of the control and experimental groups, two training sessions were aimed at the development of physical abilities, which also included exercises of a technical and tactical nature, and two control games. Exercises aimed at the development of physical abilities were held on Thursdays at 8.00 p.m. and Sundays at 12.00 a.m., which corresponded to the 1st, 5th, 8th, 12th, and 19th days of the experiment. On the 22nd day of the experiment, instead of strength training, all experiment participants were involved in a limited general physical training session. Control games were held on Tuesdays and Fridays at 8.00 p.m. The duration of sessions was 1.5 hours. In training sessions with strength exercises, the participants of the control and experimental groups performed three exercises involving the muscles of the lower extremities, which included barbell squats (Fig. 1), seated leg extensions (Fig. 2), and lying leg curls (Fig. 3). Exercises for the development of the strength endurance of the thigh muscles of football players were performed for 15 minutes in the final part of sessions.

Each week, the same exercises were used with the only difference being that the weight of the barbell used for barbell squats didn't change throughout the duration of the experiment and amounted to 40% of 1RM, while, in the other two exercises, the weight of the weights increased by 2% in each subsequent training session compared to the baseline training session (25% of 1RM) to eliminate adaptation of muscles to the load.

The members of the control and experimental groups performed three sets of each exercise to muscular failure. Squats were performed under the supervision of an assistant, which provided the opportunity to perform the maximum number of repetitions. Rest time between sets was 40 s. The duration of one repetition in the set didn't exceed 3 s. It took no more than 5 minutes to complete one exercise. Rest time between exercises didn't exceed 1 min.

Members of the experimental group made barbell squats using KAATSU Training on the 1st, 5th, 8th, 12th, and 19th days. For this purpose, pneumatic cuffs with the width of 50 mm were put on the upper thigh of their both legs (Fig. 1). The KAATSU NANO method was used [15]. Cuff pressure was constant over the course of all exercises and amounted to 400 SCU (Standard KAATSU Unit), which is equivalent to approximately 400 mmHg or 53.3 kPa. During rest pauses, cuff pressure remained unchanged. Participants of the control group performed regular barbell squats without the use of KAATSU Training. Indicators of local muscular endurance were measured from the 1st through the 40th day of the experiment.

From day 1 through day 25 of the experiment, the degree of muscular pain in the thigh muscles of the football players was evaluated on daily basis on a 10-point visual analogue scale (VAS) [17].

Statistical analysis. Experimental data were processed using the STATGRAPHICS Centurion XVI Version 16.2.04 package. The numerical parameters of the samples were calculated, the statistical law was verified, and the average values for independent and paired samples were compared. Statistical hypotheses were tested using Student's t-test.

Fig. 1. Barbell squats

Fig. 2. Seated leg extensions

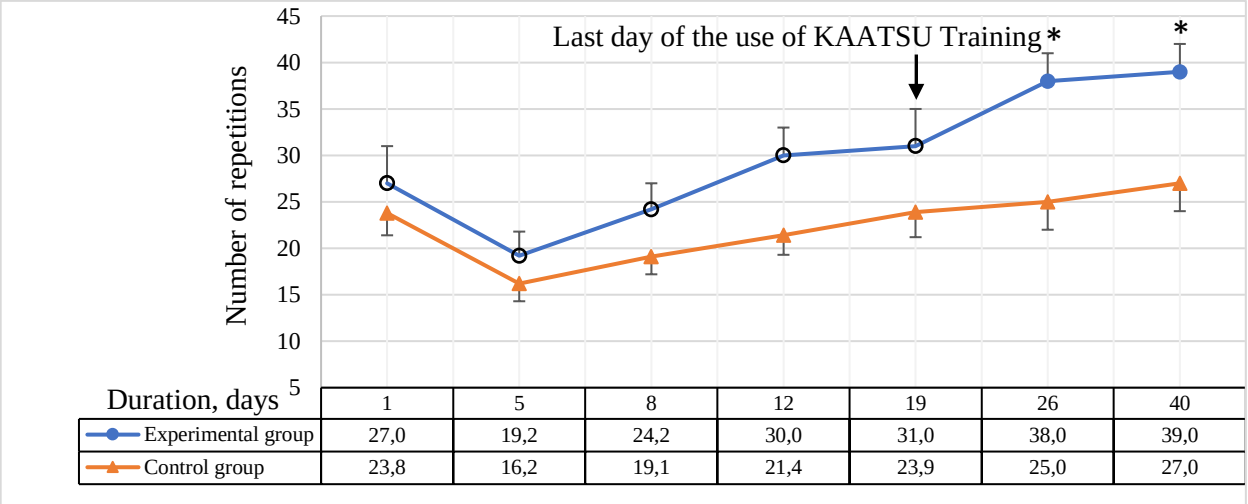
Fig. 3. Lying leg curls

3. Results

3.1. Change in the Level of Strength Endurance

Comparison of Performance metrics in Control and Experimental Groups

Prior to the start of the experiment, the level of strength endurance of the QF, which was determined by the amount of repetitions in a barbell squat with a 40% load, didn't differ significantly among the athletes in the experimental and control groups (Fig. 4). By the end of the application of the KAATSU Training (day 19), this indicator reached a value of 31±4 repetitions in experimental group athletes and 23.9±2.7 in control group athletes. However, differences between the groups weren't significant ($p>0.05$).



Duration, days	1	5	8	12	19	26	40
Experimental group	27,0	19,2	24,2	30,0	31,0	38,0	39,0
Control group	23,8	16,2	19,1	21,4	23,9	25,0	27,0

Fig. 4. Changes in the indicators of strength endurance of the QF in experimental and control groups as determined on the basis of the number of squats with a barbell with a weight of 40% of the maximum (* - significant differences between groups at a significance level of 0.05; —○— - days of application of KAATSU Training; average squat numbers are shown in the table below the figure)

In seven days after the termination of KAATSU Training, the amount of repetitions in squat in experimental group was 38±3 and became significantly higher compared to the results achieved by the control group (25±3), $p < 0.05$. Thus, the influence of KAATSU Training using the muscular failure method on the level of strength endurance of the QF in experimental group was significantly higher as compared to the regular muscular failure method.

It should be noted that the cumulative effect of KAATSU Training continued for subsequent 14 days after the termination of KAATSU Training, until the start of the team's games in the St. Petersburg First League Championship. At the end of this period (on Day 40), the average amount of repetitionss in a squat in experimental group was 39±3, while for control group it was 27±3. Differences between the experimental and control groups were significant ($p<0.05$).

Comparison of Performance by Control and Experimental Group Athletes before and after the Experiment

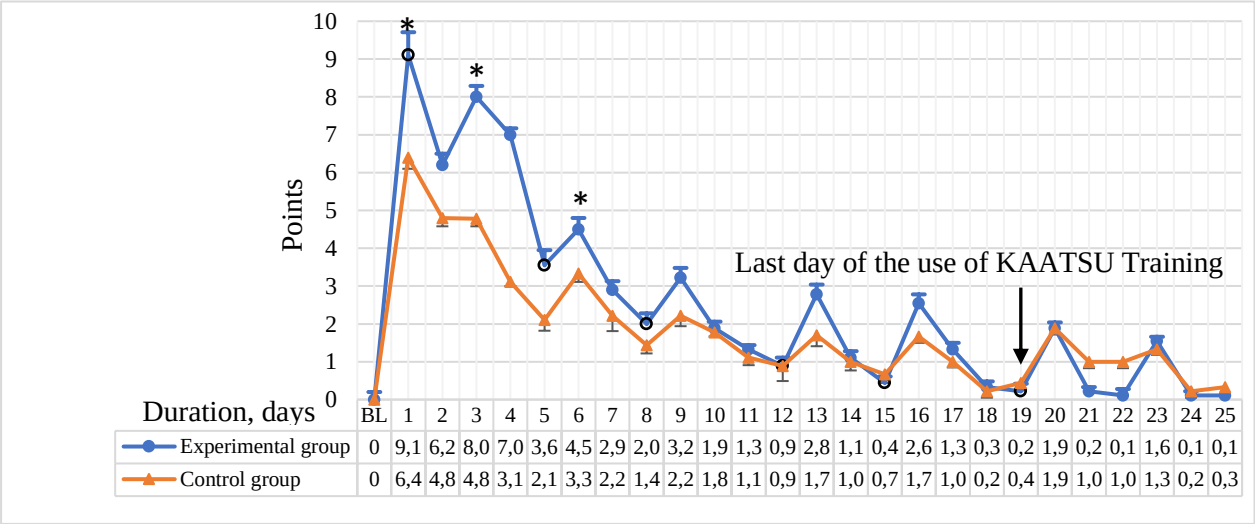
A significant decrease ($p<0.05$) in strength endurance indicators in experimental group compared with baseline indicators was noted on the 5th day of the experiment (Fig. 4). For athletes of the experimental group, the results were 19±8. A significant decrease ($p<0.05$) in strength endurance indicators among control group athletes compared with baseline indicators was noted on the 5th and 8th day of the experiment. In control group, the relevant values were 16±6 and 19±6, respectively.

A significant increase ($p<0.01$) of strength endurance of the QF in experimental group compared with baseline indicators was noted on the 26th day of the experiment. Before the end of the experiment, control group didn't show any significant changes in terms of the strength endurance of the QF as compared to baseline indicators.

3.2. Changes in the Levels of Acute Pain and DOMS

Prior to the start of the experiment, the athletes of both groups experienced no pain in the anterior and posterior groups of thigh muscles (Fig. 5). However, after performing strength exercises on the first day of the experiment, the athletes of both groups experienced acute pain. Muscular pain levels in experimental group were extremely high and amounted to 9.1±0.2 points, which was significantly higher ($p<0.05$) than the relevant indicators in control group (6.4±0.4 points). On the 8th day of the experiment, DOMS in athletes of both groups significantly decreased: down to 2.0±0.2 points in the experimental group and 1.4±0.4 in the control group. Differences in the level of DOMS between groups became unreliable ($p>0.05$). By the end of the

experiment, athletes of both groups experienced a decrease in pain levels virtually to a baseline level. Considering that strength training corresponded to the 1st, 5th, 8th, 12th, 15th, 19th, and 22nd days of the experiment, and it was clearly seen that delayed pain levels increased on the next day after each strength training session.



Duration, days	BL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Experimental group	0	9,1	6,2	8,0	7,0	3,6	4,5	2,9	2,0	3,2	1,9	1,3	0,9	2,8	1,1	0,4	2,6	1,3	0,3	0,2	1,9	0,2	0,1	1,6	0,1	0,1
Control group	0	6,4	4,8	4,8	3,1	2,1	3,3	2,2	1,4	2,2	1,8	1,1	0,9	1,7	1,0	0,7	1,7	1,0	0,2	0,4	1,9	1,0	1,0	1,3	0,2	0,3

Fig. 5. Acute pain and DOMS in the thigh muscles in experimental and control group athletes (* - significant differences between groups at a significance level of 0.05; ⟷ - days of application of KAATSU Training; BL - before physical load; average values of acute and delayed pain levels are shown in the table below the figure)

4. Discussion

The study has shown that the use of KAATSU Training over a period of three weeks led to an increase in the level of strength endurance of the QF in football players. A significant increase in strength endurance indicators of the anterior thigh muscle group as compared to baseline indicators in experimental group athletes was noted on the 26th day of the experiment, seven days after the last strength training session using KAATSU Training. The growth of local muscular endurance indicators of the thigh muscles in experimental group athletes as compared to the baseline level continued for subsequent 14 days, up to the 40th day of the experiment. Before the end of the experiment, control group athletes didn't display significant changes in terms of the indicators of local muscular endurance of QF as compared to baseline indicators.

Acute pain in athletes of both groups reached a maximum on the first day of the experiment after performing strength exercises. By the 8th day of training, the intensity of delayed DOMS decreased, and its values didn't differ from the baseline level. A slight increase in DOMS was subsequently associated with strength training to muscular failure in the control group and with strength training with the use of KAATSU Training in the experimental group.

The data obtained may be explained as follows. As far as it is known, a high power of muscular activity is associated with the alactate anaerobic mechanism of energy supply, in which adenosine triphosphate (ATP) is re-synthesised in muscle fibres as a result of the breakdown of creatine phosphate (CP). During intensive continuous strength workout to muscular failure using KAATSU Training, CP contained in muscle fibres is largely depleted. Therefore, to support efforts continuing in excess of 10 s, it is necessary to connect the second ATP re-synthesis route – glycolysis [18]. In this study, rest times between sets of strength exercises were short (40 s), while the duration of all sets of each exercise was about 5 minutes. After 5 minutes of strength training, lactate and hydrogen ions accumulate in muscle fibres [19]. Hydrogen ions cause significant damage to the membranes of muscle fibres and organelles, which contributes to the mechanical damage of muscle fibres. Subsequently, muscle fibres become inflamed. Leukocytes penetrate them from the bloodstream. The process of penetration of leukocytes into muscle fibres

is rather extended [20]. Thus, DOMS peaks in three days after the start of strength training, as clearly seen in Fig. 5. It should be noted that the diagram of changes in DOMS corresponds to the results obtained by other authors [21].

Improvement in the performance of the experimental group using KAATSU Training as compared to the group using the muscular failure method over 26 days after the start of the experiment may be explained by the accumulation of energy substrates in muscle fibres (CP and glycogen) and the improvement of muscle fibre capillarisation: an increased number of capillaries per muscle fibre [22], an increase in the diameter of blood capillaries [22], and an increase in the concentration of haemoglobin in blood plasma [9, 22]. Given that such changes require a certain amount of time, the cumulative effect of KAATSU Training on muscle fibres begins to transpire on the 26th day of training (seven days after the termination of KAATSU Training) and continues for 14 days. It should also be noted that the greater cumulative effect of KAATSU Training should affect slow twitch type I muscle fibres, where ATP re-synthesis is based on tissue respiration [22], and, apparently, type IIA muscle fibres, which also adapted to function in conditions of tissue respiration.

5. Conclusions

An influence of KAATSU Training on strength endurance of the QF of football players was reliably established. 26 days after the start of strength training using KAATSU Training, the number of repetitions of barbell squats was 38±3, which represented a significantly higher performance ($p<0.05$) compared to that of control group athletes (25±3).

Significant changes in strength endurance occurred within seven days after the termination of KAATSU Training, which we associate with the accumulation of energy substances in muscle fibres and an improvement in their capillarisation.

Changes in DOMS in muscles clearly correspond to the damage and subsequent regeneration of affected muscles.

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