Original Article

The effect of combined machine and body weight circuit training for women on muscle strength and body composition

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Published online: September 28, 2015

(Accepted for publication september 15, 2015)

DOI:10.7752/jpes.2015.03084;

Abstract:

The aim of this study was to find out whether 12 weeks circuit training, which combines hydraulic resistance machines with weight bearing exercises (CAHCT), will change body composition and strength in women and improve their health-related fitness. Nine women (age 36.2 ± 9.97 ; height 168.3 ± 7.8 cm, weight 78.7 ± 13.3 kg) underwent CAHCT 3 times per week for 12 weeks. Each subject performed a pre-test and post-test, which consisted of the measurement of body composition, maximum isometric strength for knee flexion/extension measured by an isokinetic dynamometer, maximum anaerobic power by the Wingate test and strength endurance of abdominal muscles by the partial curl up test. After 12 weeks of CAHCT no significant changes were found in body composition and in the parameters of isokinetic strength. In case of the Wingate test, peak power and relative peak power per body weight increased significantly ($d=0.76$ and $d=0.58$, respectively). Concerning the partial curl-up test, a large effect ($d=0.76$) indicated a significant change in the test score. The AHCT for women performed for 12 weeks positively influenced the motor component of health-related fitness in women who had not participated regularly in strength training. However, the changes in body composition were not significant.

Key words: physical fitness, isometric strength, anaerobic power, public health, strength training.

Introduction

Health-related fitness, built on periodical physical activity and appropriate energy intake, has a preventive impact on health problems arising from hypokinesia (Aidar et al., 2014; Boucard, Blair, & Haskell, 2006; Corbin & Pangrazi, 1992). A frequently used method to develop or maintain both performance and health-related fitness among the general population is circuit training (CT). CT allows to use a high variety of workout program such as consecutive change of exercises for the upper and lower body, agonist and antagonist muscle groups or complex and isolated exercises (Siff, 2003). Another advantage is the possibility to perform CT as a group exercise, where the trainer has a space for individual interaction with the exerciser (Klee, 2003).

CT, with regards to its modality, may stimulate strength endurance, strength, endurance and may compensate muscle imbalances and change body composition (Kerksick et al., 2009; Kraemer, Ratamess, & French, 2002). It was also proved that resistance CT may be an effective training strategy not only for the promotion of strength, but at the same time for cardiovascular adaptations and body composition changes (Alcaraz, Sanchez-Lorente, & Blazeovich, 2008; Mayorga-Vega, Viciano, & Cocca, 2013; Sawczyn et al., 2014). On the other hand, the disadvantage of resistance CT is a lack of time to set up individual resistance (when there is no resistance machine) including its progressive increase. The reason is that physical training, strength training included, is generally most effective if the load is individualized and work out parameters are periodically changed toward the training goal (Igor & Vladimir, 2010; Siff, 2003; P. Stastny, Lehnert, Zaatar Zaki, Svoboda, & Xaverova, 2015). Although periodization was proven to be an effective approach in longer training programs with resistance CT (Marx et al., 2001), this requirement might not be necessary in untrained population, where the health aspect of exercise is the priority and adaptability to exercise routine in this population is much lower than in athletes.

A plethora of modifications of resistance CT training are used by trainers to match specific needs for women, especially the need for relatively low-intensity exercises without increasing the resistance, but with low rest intervals. If there is no increase of exercise resistance, there should be another loading parameter, which might increase the effectiveness of the workout program such as an antagonistic hydraulic training system, which works in a concentric antagonistic regime. Thus, CT can combine a hydraulic resistance machine with weight bearing exercises, and complex and isolated exercises can be used. This training compromise is applied in women's group exercise as combined antagonist hydraulic resistance circuit training (CAHCT). The effect of

CAHCT was previously examined in a fourteen-week intervention, which suggested that only a combination of CAHCT and diet restriction can change body composition effectively (Kerksick et al., 2009). The aim of this study is to find out whether CAHCT applied in women for 12 weeks will change body composition and strength as an important characteristic of health-related fitness.

Material & methods

The research was performed using an intervention study design with a pre-test and post-test. The pre-test was performed three days before the first training session. The participants performed three 40min training sessions per week for three months.

Participants

Thirteen healthy novices (age 36.2 ± 9.9 years, height 168.3 ± 7.8 cm, weight 78.7 ± 13.3 kg) were recruited from a women's fitness club FitCurves in Olomouc. Participant recruitment was done by public announcement. The inclusion criterion was absence of regular strength training for at least 5 months. Only 13 women out of the 45 interested in participation matched the estimated criteria, 9 women finished the study and were included into the analysis. The reason for drop out (four participants) was insufficient attendance at the training sessions, i.e. less than 20% of the training sessions. Before the first measurement, the participants were informed about all aspects of the study, and they signed an informed consent. The study design, measurement techniques and the participants' informed consent were approved by the Ethics Committee of the Palacky University in Olomouc and conformed to the Declaration of Helsinki regarding the use of human subjects.

Circuit training program

Eight antagonist hydraulic resistance machines were consecutively altered with either weight bearing or body weight exercise (Tab. 1). The hydraulic antagonistic resistance machines allow only a concentric muscle action in a "push and pull" system, for example: sitting elbow flexion/extension gave constant resistance for concentric biceps flexion and concentric triceps extension. This system is different from free weight training, where concentric elbow flexion (biceps curl) is followed by eccentric biceps work, while the elbow extends. Each session was performed in the same exercise order and with the same external resistance. The participants were instructed to perform as many repetitions as possible in 30s intervals, followed by 5s rest when changing exercise stations. Four sets of this circuit were performed during a total of 40min, the participants rested for 30s between the sets. The warm-up before the program consisted of 5min. of cycling and a 5min cool-down period with static stretching. The training program was performed on 3 non-consecutive days per week for 12 weeks between February and May 2014.

Table 1. Circuit training work out with targeted muscle groups.

Order	Exercise	TUT (s)
1	Squats ^{HM}	15/15
2	Sit ups	30
3	Sitting elbow flexion/extension* ^{HM}	15/15
4	Mini squat jump	30
5	Sitting hip flexion/extension* ^{HM}	15/15
6	Step up 40cm	30
7	Sitting hip abduction/adduction* ^{HM}	15/15
8	Crunches	30
9	Sitting horizontal push and pull* ^{HM}	15/15
10	Lunges with body weight	15/15
11	Sitting vertical push and pull* ^{HM}	15/15
12	Reverse sit ups	30
13	Leg press ^{HM}	30
14	Plank	30
15	Sitting knee flexion/extension* ^{HM}	15/15
16	Shoulder raise on Swiss ball	30

Table 1 caption: *Exercises were performed with resistance in both movement directions; HM hydraulic machine exercise; TUT = time under tension, exercise time.

The participants were instructed not to perform other physical activities in addition to the circuit training program and not to change their nutrition habits.

Measurements

Body composition was tested prior to the physical tests, which took place in following order: Isokinetic test, abdominal strength endurance test and 30 s anaerobic Wingate test (WG30). The warm-up procedure was supervised by a strength training instructor and included 6min of cycling on an ergometer, quadriceps and hamstring stretching and 12 squats with a progressively increasing range of motion.

Body composition

Body composition was measured by the InBody 230 multi-frequency bioelectrical impedance instrument (Biospace, South Korea). The monitored parameters were the percentage of body fat, fat free mass, lean muscle mass and fat mass. Body composition was measured as the first parameter in the testing procedure and, in compliance with recommended guidelines (Heyward & Stolarczyk, 1996), in a state without disturbing hydration or sweat.

Warm-up

Prior to the testing procedure, the participants completed non - specific warm - up exercises, which included cycling on a stationary bicycle ergometer for 6 minutes at a self - regulated low to moderate intensity, 5 minutes of dynamic stretching exercises which targeted the main muscle groups involved during the testing procedure and twelve squats. The warm - up routine was supervised by a researcher.

Isokinetic test

Maximum isometric strength was measured in the sitting position for knee flexion and extension using an isokinetic dynamometer Isomed 2000 (D & R Ferstl GmbH, Hemau, Germany). The backrest of the dynamometer seat was set at an angle of 75°; the angle of the hip joint was 100°. The arm of the dynamometer lever was fixed to the distal part of the shin, and the lower edge of the shin pad was placed 2.5 cm over the medial apex malleolus. The subjects were secured with belts in the pelvic region and the thigh region of the tested lower limbs. Adjustable straps and pads were placed on the shoulders, the participants held hand grips located along the seats. The mechanical axis of the dynamometer was aligned with the knee axis according to the standard position for knee flexion/extension.

Isometric strength was measured after one habituation set in 65° for knee extension and 35° for knee flexion. The testing protocol consisted of two contraction sets (warm - up and testing). In both sets the participants performed two 5s maximum voluntary isometric contraction with a 55s rest interval. The right lower limb was tested as the first and the left lower limb as the second, there was a 2 min interval between the right and left lower limb tests. The participants were provided with concurrent visual feedback in the form of an isokinetic strength curve displayed on the dynamometer monitor. Verbal encouragement was also provided. The measured parameters were the peak Torque (PT) and Average Torque (AT). Prior to the testing procedure, the participants completed non - specific warm - up exercises, which included cycling on a stationary bicycle ergometer for 6 minutes at a self - regulated low to moderate intensity, 5 minutes of dynamic stretching exercises which targeted the main muscle groups involved during the testing procedure and twelve squats. The warm - up routine was supervised by a researcher.

Abdominal strength endurance

A partial curl-up was performed in the supine lying position with a 90° knee angle. One repetition was counted for a smooth 12 cm concentric/eccentric transition of extended upper limbs on the floor, while controlled curl-ups to lift the shoulder blades off the mat (the trunk makes a 30° angle with the mat) in time with a metronome (20 curl-ups per minute) were performed. The aim was to perform as many repetitions as possible in a given rhythm, to a maximum of 75 (Harman, Garhammer, & Pandorf, 2000). The lower back stretching for 20s was applied two times prior to the abdominal test to avoid diminished performance due to an antagonistic imbalance.

30s Wingate test (WG30)

To diagnose the anaerobic power output of the tested group the WG30 test was used. The test was conducted on a calibrated friction loaded cycle ergometer (Monark exercise AB, Vansbro, Sweden) interfaced with a microcomputer. The cycle was equipped with toe-clips to prevent the subjects' feet from slipping. The test consisted of a 30s maximum sprint against a constant braking resistance dependent on the subjects' body mass (0.075 kg.kg⁻¹ of body mass) according to the optimization tables by Bar-Or (Bar-Or, 1987; Dotan & Bar-Or, 1983). The test began from a rolling start, with maximum individual repetition against minimum resistance. When the maximum pedal rate was achieved, a countdown of "3-2-1-go!" was given before dropping the weight basket with a load. Prior to the test the participants were instructed to pedal as fast as they could for 30s. Power output was calculated each 5s as a meanvalue. The best 5s was used as peak power, which is related to maximum and explosive strength abilities of an individual (Petr et al., 2014; Petr Stastny, Fiala, & Petr, 2010).

The values can either be expressed as absolute values of peak power (Pmax) expressed in Watts (W) or relative peak power per body weight (Pmax.kg⁻¹) expressed in Watts per body weight (W.kg⁻¹). The total work during WG30 was expressed as a total anaerobic capacity (ANC) expressed in kilojoules (kJ) or relative ANC expressed in joules per body mass (J.kg⁻¹).

Statistical analysis

Statistical analyses were done using the Statistica 12 software (StatSoft Inc., Tulsa, OK, USA). The Cohen d was used to compare the pre-test and post-test, where d = 0.2 indicated a small effect, d = 0.5 an intermediate effect and d = 0.8 = a large effect (Cohen, 2013). With respect to the duration of the CAHCT and the knowledge about the effects of similar strength training programs, a moderate effect will be considered significant.

Results

After the 12 weeks of CAHCT no significant changes were observed in body composition in the monitored group of women. A small effect of the training program on muscle mass, fat mass and fat free mass was confirmed (Table 2). Similarly, in the parameters of isokinetic testing (Tab. 3) only a small effect was found in some cases (right lower limb: PT of knee flexion and AT of knee flexion and extension; left lower limb: PT in knee extension, knee flexion and AT in knee flexion).

Table 2. Differences in body composition before and after circuit training program (n = 9).

Parameters	Pre (mean ± SD)	Post (mean ± SD)	ΔI-2	d
Weight (kg)	78.74 ± 13.34	79.07 ± 13.11	0.32	0.02
BMI (kg/m ²)	27.97 ± 5.58	28.01 ± 5.40	0.04	0.01
Muscle mass (kg)	25.91 ± 3.13	26.82 ± 3.45	0.91	0.24
Fat mass (kg)	28.69 ± 7.68	27.70 ± 7.84	0.99	0.11
Fat mass (%)	37.31 ± 5.54	35.80 ± 5.89	1.46	0.23
Fat free mass (kg)	47.13 ± 5.20	48.70 ± 5.61	1.58	0.25

Table 2 caption: SD = standard deviation; ΔI-2 = mean differences between pre-test and post-test; d = Cohen's d.

Table 3. Differences in isokinetic peak and average torque before and after circuit training program (n = 9, torque in N.m-1).

Parameters	Pre (mean ± SD)	Post (mean ± SD)	ΔI-2	d
PT knee ext RL	185.22 ± 31.16	198.22 ± 24.94	13.00	0.46
PT knee ext LL	188.44 ± 30.59	195.44 ± 24.49	7.00	0.25
PT knee flx RL	102.00 ± 19.56	103.00 ± 21.63	1.00	0.05
PT knee flx LL	99.00 ± 25.67	106.00 ± 21.56	7.00	0.30
AT knee ext RL	167.67 ± 29.70	178.78 ± 19.77	11.11	0.45
AT knee ext LL	170.56 ± 28.08	174.1 ± 19.60	3.56	0.15
AT knee flx RL	88.67 ± 15.52	92.22 ± 18.71	3.56	0.21
AT knee flx LL	90.33 ± 21.60	95.56 ± 20.82	5.22	0.25

Table 3 caption: SD = standard deviation; ΔI-2 = mean differences between pre-test and post-test; d= Cohen d, PT = peak torque, AT = average torque, Ext = extensors; Flx = flexors, RL = right leg, L = left leg, d= Cohen's d.

In the parameters of the Wingate test, PP and PP/kg increased significantly (d=0.76 and d=0.58, respectively), while only a small effect of the training program on AnC and AnC.kg⁻¹ was confirmed (Tab. 4). In case of the partial curl-up test, a large effect (d=0.76) indicates a significant change in the test score, where the number of repetitions in this test increased by 17.8 reps in the mean from the pre-test (mean ± SD, 48.9 ± 21.6) and post-test (mean ± SD, 64.8 ± 13.7).

Table 4. Differences in Wingate test results before and after circuit training program (n = 8).

Parameters	Pre (mean ± SD)	Post (mean ± SD)	ΔI-2	d
Peak power (W)	565 ± 84	630 ± 87	65.21	0.76
Relative peak power (W/kg)	7,50 ± 1,50	8,34 ± 1,41	0.85	0.58
Anaerobic capacity (kJ)	11926 ± 1262	12236 ± 1506	320.80	0.23
Relative anaerobic capacity (J/kg)	157 ± 20	161 ± 21	4.42	0.22

Table 4 caption: SD = standard deviation; ΔI-2 = mean differences between pre-test and post-test; d= Cohen's d.

Dicussion

The results showed that after 12 weeks of AHCT, body composition did not change significantly. Therefore, this training program itself, without a nutrition plan, was not effective to reduce FM or increase FFM. Same result have been found in previous study, where the strength and endurance fitness program without nutritional support was found to be ineffective for composition change in older men population (Kerksick et al., 2009; Zajac, Wilk, Socha, Maszczyk, & Chycki, 2014). CAHCT seemed an insufficient stimulus to evoke muscle hypertrophy and to avoid possible decrease in FFM. This finding might be considered unexpected because resistance exercises are known for their high energy demands (Reis, Júnior, Zajac, & Oliveira, 2011), during which middle-aged woman reduce fat percentage (Soares Costa de Mendonça, Targino de Araújo Júnior, de Sousa, do Socorro, & Fernandes, 2014). It is not easy to justify this result because from the point of view of the training variables (intensity, volume, frequency), the training program seemed to fulfil the generally accepted recommendations for training programs focused on increase in muscle mass (Wernbom, Augustsson, & Thomeé, 2007). The only questionable training program variable, which was difficult to evaluate because of the specifics of the hydraulic machines used, was intensity and its increase. We could also speculate that the result could be influenced by a potential different effect between males and females. However, a similar increase in muscle cross sectional area after the same strength training program was proven in males and females in a study by Wernbom (Wernbom et al., 2007).

Nevertheless, the above mentioned finding is similar to a finding in a previous study by Kerksick (Kerksick et al., 2009) see Tab. 5. This negative finding might be influenced by inaccuracy of BIA (Woodrow, 2007), where for example more exact equipment such as dual energy X ray absorptiometry might result in more precise and more specific findings, for example detailed estimation of intra-abdominal fat. On the other hand, BIA was previously reported for good estimation of fat loss after aerobic programs (Hlubik, Stritecka, & Hlubik, 2013). Overall, the effect of CT on body composition changes was not significant. However, a positive trend was observed in case of fat free mass with simultaneous reduction of fat fraction representation.

Table 5. Change in body composition – comparison between current study and study by Kerksick (2009)

Study	Current (2015) n=9	Kerksick (2009) n=161
Length of intervention	12 weeks, 3 x/ week	14 weeks, 3 x/ week
Body mass (kg)	+0.3	-0.2
FFM (kg)	1.6	0.1
FM (kg)	-1.0	-0.8
Fat mass (%)	-1.5	-0.6

Table 5 caption: FFM – fat free mass; FM – fat mass

An interesting finding of our study was that the lower limb isometric strength increased only in the case of the right lower limb, which was reported as the dominant one by the participants. Our participants had a high level of initiation of maximum strength compared with normative values (Danneskiold-Samsøe et al., 2009), which might also be related to no changes in body composition. Especially one participant had initial knee flexion strength 237 N.m in the right limb and 253 N.m in the left limb, which would be appropriate even for an athlete. Moreover, the average values reported as normative were exceeded by 26% for knee extension PT and 36% for knee flexion PT in our group. In comparison with men's population (Alangari & Al-Hazzaa, 2004), our group reached 35 percentile in knee extension PT in the post-test results, 70 percentile in right knee flexion PT and 80 percentile in left knee flexion PT. On the other hand, some individuals showed a large increase in maximum strength (up to 56Nm), which is typical for novices at the beginning of a strength training program. When comparing these results, differences in the isokinetic machines and testing procedures, as well as some details such as the use of verbal and visual feedback or comfort in the test body position have to be considered (Lehnert, Urban, Procházka, & Psotta, 2011). The isometry test was performed unilaterally, where there was no change in the bilateral strength deficit as in previous studies (Maly, Zahalka, & Mala, 2014; Maly, Zahalka, Mala, & Cech, 2014).

The WG30 results were assessed only in 8 persons, because one subject failed to complete the test and a direct re-test was not possible. In all cases CAHCT increased the participants' PP and strength endurance, thus CAHCT was effective for untrained women to improve this fitness indicator. The results of WG30 were compared with the normative values reported in previous studies (Maud & Shultz, 1989; Zupan et al., 2009) see Tab. 6. The absolute PP resulted in an average value, relative PP in a fair value AnC in an average value, but relative AnC in a poor value. This training result is not consistent with the increased strength endurance in the specific Partial curl up test. Regarding the fact that the WG30 test is performed by lower limb muscles, it is possible that the CAHT program targets the abdominal muscles rather than the lower limbs.

Table 6. Group average results of peak and average power output in different studies.

	Peak power		Anaerobic capacity	
	Absolute (W)	Relative (W.kg-1)	Absolute (W)	Relative (W.kg-1)
Current study	629.7	8.35	430.0	5.67
Maud & Shultz (1989)	454.5	7.61	380.8	6.35
Zupan et al. (2009)	598.0	9.59	445.0	7.16

The greatest increase in fitness test results was found in average values of the performed repetitions in the Partial curl-up test (33%). In this test, the participants reached on average 90 percentile in the post-test. This effect is probably caused by specific adaptation to sit-ups and other abdominal exercises included in the training programme. While WG30 is a non-specific test, which should mainly assess metabolic adaptation, the curl-up test also includes specific adaptation to tested movements (Folland & Williams, 2007).

The limitations of this study include a low number of participants. The reason is that only a small number of addressed women matched the criteria to be estimated as women who do not regularly perform physical exercises, during the recruiting process 32 volunteers were rejected due to regular participation in physical exercise and/or previous experience with CAHCT, and 4 participant were rejected due to low training attendance. Other limitations include individual response to CAHCT, which might be predisposed by genetics (Petr et al., 2014), strength ratios (Petr Stastny, Michal Lehnert, et al., 2015; Petr Stastny, James J Tufano, et al., 2015), psycho-physiological parameters (Bretz et al., 2014) or previous sport history. The results of the pre and post-test could also be affected by the phases of the menstrual cycle (Da Silva-Grigoletto et al., 2008; de Lima Costa, Santos, Rocha, & da Silva, 2015; Jaskólska et al., 2004); however, this aspect was not taken into account in our study. Another limitation is also that while the training volume is defined by exact duration of CAHCT, the intensity may vary depending on exercise frequency and individual maximum strength and effort.

Conclusions

The results of the current study indicated that the AHCT for women, performed for 12 weeks three times per week, positively influenced the motor component of health-related fitness in women who had not regularly participated in strength training. This modification of CT did not result in significant changes in body composition. For future studies we suggest verification of the training effect of CAHCT applied for a longer period.

Acknowledgement

This study was funded by project POST-UP II, No.CZ.1.07/2.3.00/30.0041, co-funded by the European Social Fund and the Government of the Czech Republic.

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