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THE EFFECTS OF RESISTED SPRINT TRAINING ON SPEED PERFORMANCE IN WOMEN

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ABSTRACT

Purpose. The main aim of the study was to examine the effects of resisted and standard sprint training on the kinematics of sprint-running acceleration in women. **Methods.** Thirty-six untrained but physically active female college students were randomly assigned to one of three groups: a running resisted training group (RTG, *n* = 12), a standard training group (STG, *n* = 12), and a control group (CON, *n* = 12). All participants in the experimental groups trained three times a week for four weeks, followed by a 1-week training break, after which they trained again for four weeks. Pre-training, post-training and detraining (three weeks after completing the training programs) measures of mean running velocity, stride length, stride frequency, knee angle at toe off and footstrike, ground contact time, and flight time were analyzed by a 20 m sprint test. **Results.** The RTG improved mean running velocity and increased stride length and knee angle at toe off. Simultaneously, the RTG featured decreased stride frequency and increased ground contact time. The STG demonstrated an increase in mean running velocity due to higher stride frequency and a decrease in ground contact time. All of the measured parameters did not significantly decrease after the three-week detraining period. The control group featured no changes. **Conclusions.** Both resisted and standard sprint training improves speed in sprint-running acceleration in women by improving different sprint kinematic parameters.

Key words: speed, acceleration performance, kinematics, stride length, stride frequency

Introduction

It is speed that to a large extent determines athletic success in sports [1]. Running speed is in a large part determined by running form, as it determines the body's movement as a function of time and space by the diagonal, cyclical stride of the lower limbs. Running stride and therefore speed, from a mechanical point of view, is determined by two antagonistic kinematic parameters, stride length and stride frequency. This makes running at the fastest speed possible only by exhibiting a combination of optimum stride length and frequency. They are not, however, constant values; the contribution of each in creating a "golden ratio" depends on running gait phase as well as sex, age, competitive level. It has been suggested that stride frequency is dependent on nerve conduction velocity and thus strongly linked to genetic factors. Hence, research has focused more on the second parameter – stride length – and how it can be improved by adapting existing training techniques [2].

One of the most basic ways used to lengthen running stride is through the use of resisted training, a type of conditioning performed by adding external load by pulling a sled, tire, or a specially designed parachute; resisted bands; or by running uphill or against the wind. The greatest benefits provided by such forms of conditioning are increases in the strength and power of the leg extensor muscles at toe off, mainly in the first stage of running – the acceleration phase [3, 4]. This relationship between increasing strength and power with running velocity has been observed by many researchers [5–7]. On the other hand, Saraslanidis [8], among others, did not find an increase in running velocity after an eight-week resisted running program, although measurements were taken only after completing a run. In tests carried out by Zafeiridis et al. [9], an eight-week program led to improvements in maximum velocity during acceleration (0–20 m) and in stride frequency, but not stride length. Similarly, Spinks et al. [10] noted a significant improvement in velocity when running short distances (up to 15 m) but noted no significant changes in stride length or frequency.

In view of the lack of clear results on the effects of resisted sprint training on improving running velocity, as well as a lack of research and recommendations that take sex into account (all of the above mentioned tests were performed only on males), the aim of present study was to evaluate the effectiveness of resisted sprint training in women by measuring changes in running velocity and other kinematic parameters. With this in mind, the following research questions were formulated:

1. Does resisted running with the use of an external load improve speed in physically active women?
2. Does the type of the sprint training program differentiate the kinematic parameters of stride in women?

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3. What are the long-term effects of resisted sprint training when compared with standard sprint training?

Material and methods

The research group consisted of 36 female physical education students who did not practice professional sports. However, in light of the participants' field of study (8–10 h of physical activity per week), they can be specified as highly physically active individuals. The study group was randomly divided into three sub-groups: the first experimental group trained resisted running with an external load (RTG, *n* = 12), the second trained under normal sprint training technique (STG, *n* = 12), and the third was a control group (CON, *n* = 12) who participated only in the measurement sessions. Age, body height, and body mass are presented in Table 1. All were asked to refrain from participating in any physical activity outside of their normal university classes. The participants were informed about the aim of the study and research procedure, which was accepted by the Research Ethics Committee at Józef Piłsudski University of Physical Education in Warsaw, Poland.

Testing

The participants' sprint performance was tested on three separate occasions: three days before the training programs for the experimental groups were to begin (pre-training), three days after the programs were completed (post-training), and then three weeks later (detraining). The test consisted of a 20-m sprint (R_{20}), run at the fastest speed possible. Participants began from a standing start position with the legs in stride, the front leg located just before the starting line and the rear leg approximately 30 cm behind. They were checked for proper starting posture, with a slight bend at the knees and the torso slightly bent forward. All participants performed the task in appropriate sportswear (t-shirt and shorts).

Table 1. Characteristics of the participants

Group	Age (years)	Body height (m)	Body mass (kg)
RTG (*n* = 12)	22.0 ± 0.9	1.67 ± 0.07	61.5 ± 4.7
STG (*n* = 12)	22.3 ± 0.8	1.66 ± 0.06	61.3 ± 5.4
CON (*n* = 12)	21.9 ± 0.7	1.68 ± 0.08	62.1 ± 4.9

RTG – running resisted training group
STG – standard training group
CON – control group

The participants completed two trials; they were allowed to start at their leisure, no starting command was given. The run with the highest mean velocity was recorded for later analysis. All tests were performed at a track and field stadium at an ambient air temperature of 21–23 degrees Celsius with minor wind (0.3–0.6 m · s^{-1}), measured by an electronic anemometer (Slandi 2000, Poland) in the direction of track. Seven to eight min of rest was provided between trials [11]: the first four min consisted of absolute rest, the next three or four min were spent preparing for the run by performing dynamic stretching exercises, each of which were followed by shaking the leg muscles.

A warm-up prior to measurement taking was performed, beginning with a low-intensity run (5 min) and dynamic stretching exercises (7–8 min) of the most involved muscle groups when sprinting, i.e., hip, knee, and ankle extensors and flexors [12]. The rest interval between each stretching exercise was 10–15 s. After the general warm-up, skipping exercises were performed (1 x 20 m) and another run at submaximal intensity (1 x 40 m). The warm up was performed while wearing a sweatshirt and sweatpants, which were removed just before completing the sprint test.

The sprint test (R_{20}) was preceded by a pilot study whose aim was to determine the reliability of the R_{20} test as well as calculate the external load for the participants who would take part in the resisted sprint training program. Previous studies have suggested an optimal load that can reduce normal running velocity by 10% [14]. For this purpose, a sled was constructed from two 70-cm circular runners held together by perpendicular tubing 45 cm in length. Located in the center of the sled was a vertical shaft on which disc weights (plates) were placed. A 5-m harness was used to connect the sled to a leather belt worn above the hip bones. The total weight of sled without additional plates was 3 kg. The participants performed three runs with an external load of 5%, 7.5%, and 10% body mass, performed in random order. The procedure and conditions for this pilot test were the same as when performing the R_{20} test. External load was determined by multiplying body mass by the percent of external load to be used (e.g., 5% body mass = 0.05), subtracting the mass of the sled [15]. Based on the cri-

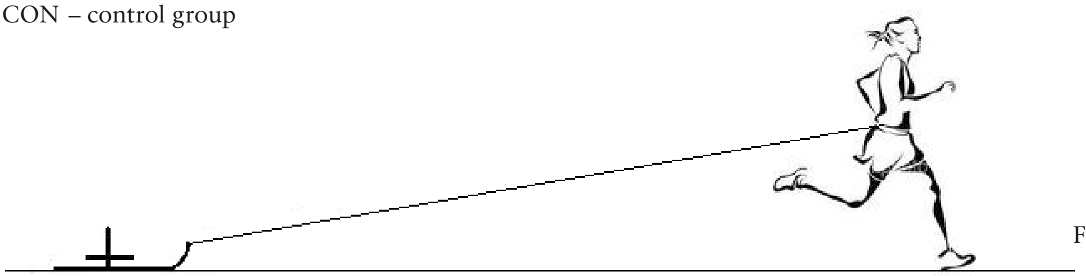


Figure 1. Resisted running with an external load

teria for selecting resisted running load (10% reduction in mean running velocity), a weight of 7.5% of body mass was used for eight of the participants, while for the remaining four a weight of 10% of body mass was used.

Kinematic analysis

Two digital cameras were used to record the sprint trials at a sampling rate of 100 Hz; video was later analyzed using SteamPix 3.34.0 software (Norpix, Canada). The cameras were set perpendicularly to the track at a distance of 24 m (Fig. 2), each filming a 10-m portion of the track including 1 m before and 1 m after the start and finish lines with an overlap of 2 m at the center. Only every 3rd and 4th stride were considered for analysis.

Five tracking markers were placed on the right side of the body during measurement taking: at the height of anterior superior iliac spine, the greater trochanter of the femur, the lateral condyle of the tibia, the lateral malleolus, and the 5th metatarsal [15, 16]. Later, two-dimensional kinematic analysis of the recorded test runs was performed using APAS-XP marker-tracking software (Ariel Dynamics, USA). The video was scaled with the use of a flat calibration system.

The following kinematic parameters were measured during the tests, all of which were performed only on the right side of the body: *mean running speed* ($m \cdot s^{-1}$), calculated by first adding ground contact time and flight, then having this value divide stride length [16]; *stride length* (m), determined by the distance from the tip of the front shoe at toe off to the tip of the opposite shoe at footstrike; *stride frequency*, calculated on the basis of the number of steps in a certain period of time; *knee angle at toe off and footstrike*, measured by the angle between the thigh and lower thigh by a straight line passing through the greater trochanter of the femur and the lateral condyle of the tibia and a line passing through the lateral condyle of the tibia and lateral malleolus; *ground contact time*, as the time between footstrike and toe off; and *flight time*, measured as the time between toe off by one foot until footstrike by the opposite foot. The reliability of the above-measured parameters, determined by intraclass correlation coefficients (ICC), was found to be high and ranged between 0.79–0.92 [13].

Sprint training programs

Due to the intensive nature of the sprint training programs, the participants in the two experimental groups (RTG and STG) concluded a three-week compensatory physical fitness course, held twice a week, before their actual training programs were to begin. Average duration of each class was approximately 50 min. The course focused on basic exercises aimed at improving sprint

Table 2. Sprint training programs implemented by both experimental groups (resisted and standard sprint training)

Week	Training program Set x repetition x distance [m]	Rest intervals* Set [min] x repetition [s]
1	3 x 3 x 20	3 x 60
2	4 x 3 x 20	3 x 60
3	3 x 3 x 25	3 x 90
4	4 x 3 x 25	3 x 90
5	Rest	Rest
6	3 x 3 x 30	4 x 120
7	4 x 3 x 30	4 x 120
8	3 x 3 x 35	4 x 150
9	3 x 3 x 20	4 x 150

* rest provided in accordance with previous recommendations [11]

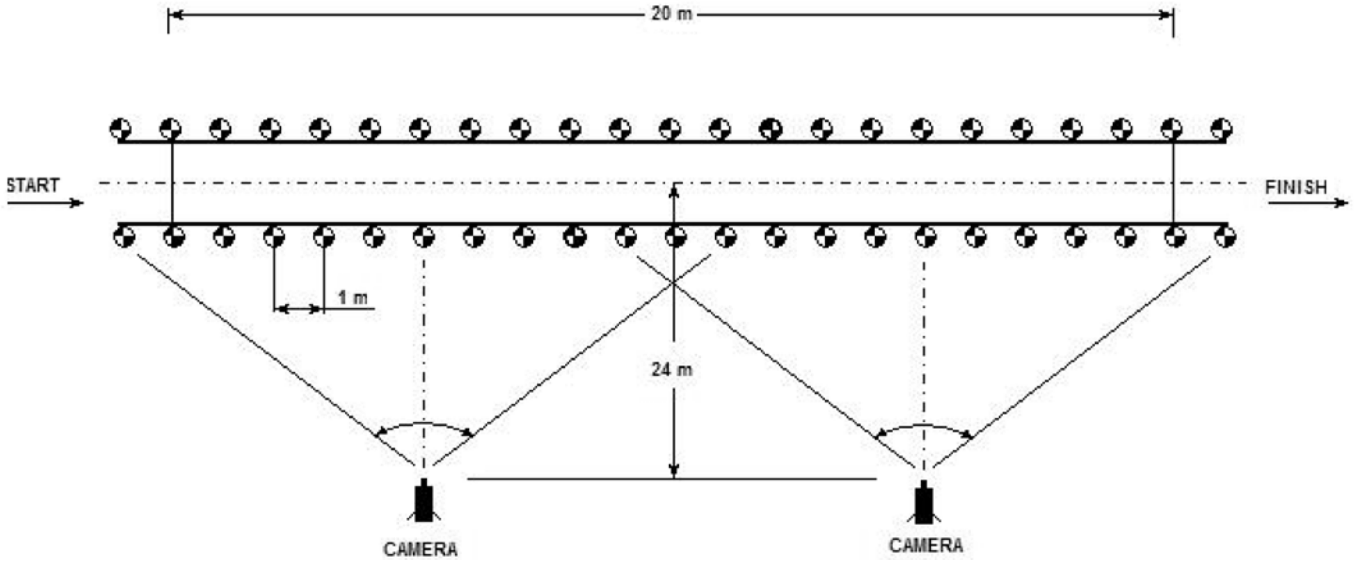


Figure 2. Graphic representation of the track used to measure sprint velocity at a distance of 20 m (R_{20})

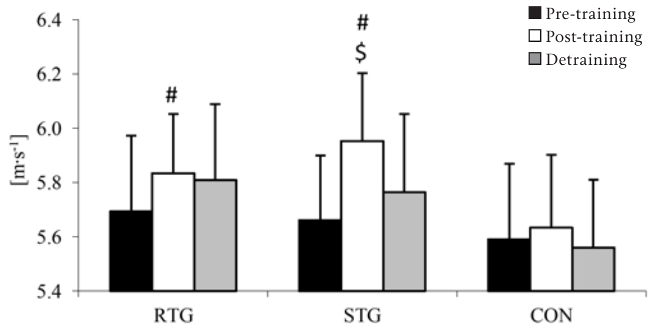
performance, with particular attention placed on proper execution. After completing the compensatory physical fitness course, groups RTG and STG began a nine-week speed training program (with a rest interval during the fifth week where no training was performed) with classes held three times per week (Tab. 2). The design of the sprint training programs included periodization, as its performance benefits have been scientifically verified in a number of studies [1, 17]. The training programs were conducted by a coach specializing in short-distance running. Time was measured with a 83520 stopwatch (Casio, Japan). Immediately after finishing a sprint, the participants received feedback on their time as well as motivational support, such as "maintain the same time" or "try to run faster". In addition, sprint technique was continuously monitored, such as performing larger extensions of the rear leg at the knee at toe off or maintaining correct posture along the axis made between the ankle and hip of the propulsive leg (at toe off). The RTG performed all runs with the sled, whose weight was previously calculated for each individual; the STG ran with no external load.

Statistical analysis

The collected data were summarized as mean and standard deviation (SD). The Shapiro-Wilk test was used to confirm whether the variables were normally distributed. Significant differences among the analyzed stride kinematic parameters were analyzed by a two-way repeated measures ANOVA. Tukey's *t* test was applied if the results were statistically significant. Statistical significance was set at $p \leq 0.05$. All statistical analysis was performed using Statistica v. 5.1 PL software (Statsoft, Poland).

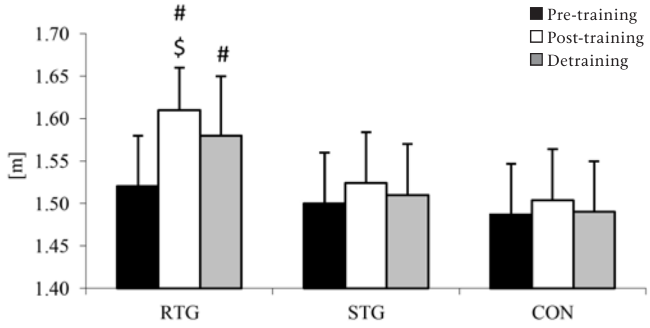
Results

Figures 3–9 present the results as means ± SD for the kinematic parameters measured during the R_{20} test before (pre-training) and after (post-training) the training programs as well as three weeks after completion (detraining). Statistical analysis found significant effects between: group (RTG, STG, CON) x time (post-training, post-training, and detraining), x mean running velocity ($F_{4.66} = 4.92$; $p < 0.01$), x stride length ($F_{4.66} = 8.47$; $p < 0.001$), x stride frequency ($F_{4.66} = 2.72$; $p < 0.05$), x knee angle at toe off ($F_{4.66} = 3.42$; $p < 0.01$); x knee angle at footstrike ($F_{4.66} = 4.42$; $p < 0.01$). Both experimental groups (RTG and STG) significantly increased their mean running velocity upon completing their training programs by 2.5% and 4.9% ($p < 0.05$), respectively, with the velocity attained by the STG being significantly higher ($p < 0.05$) than the control group. Mean running velocity of both experimental groups three weeks after completing training (detraining) did not significantly differ ($p > 0.05$) from post-training velocity. For stride



$ – significantly different ($p < 0.05$) from the control group
# – significantly different ($p < 0.05$) from pre-training values
RTG – running resisted training group
STG – standard training group
CON – control group

Figure 3. Mean ± SD running velocity measured pre-training, post-training, and three weeks after completing training (detraining)



$ – significantly different ($p < 0.05$) from the control group
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RTG – running resisted training group
STG – standard training group
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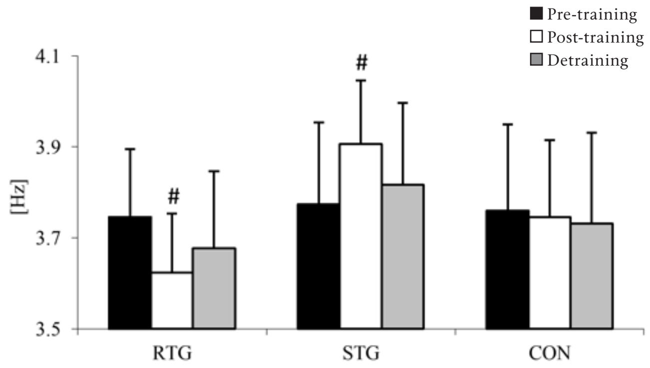
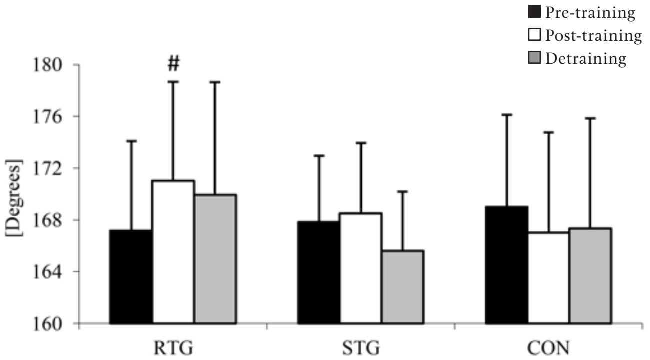
Figure 4. Mean ± SD stride length measured pre-training, post-training, and three weeks after completing training (detraining)



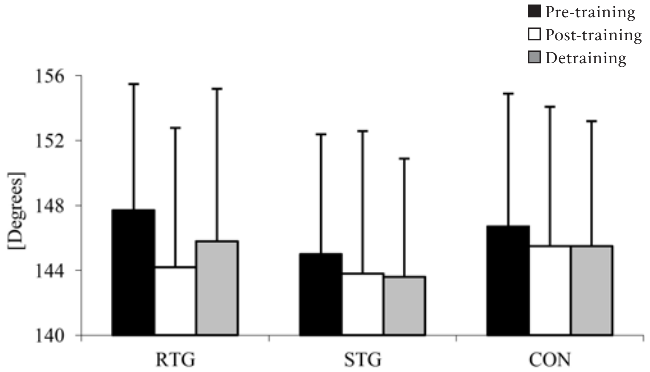
– significantly different ($p < 0.05$) from pre-training values
RTG – running resisted training group
STG – standard training group
CON – control group

Figure 5. Mean ± SD stride frequency measured pre-training, post-training, and three weeks after completing training (detraining)



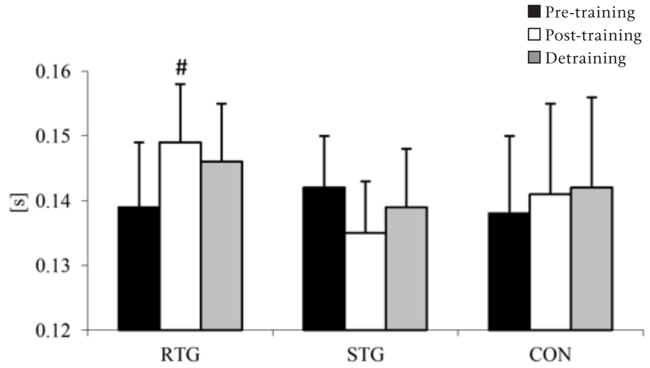
\# – significantly different (p < 0.05) from pre-training values
RTG – running resisted training group
STG – standard training group
CON – control group

Figure 6. Mean ± SD knee angle at toe off measured pre-training, post-training, and three weeks after completing training (detraining)



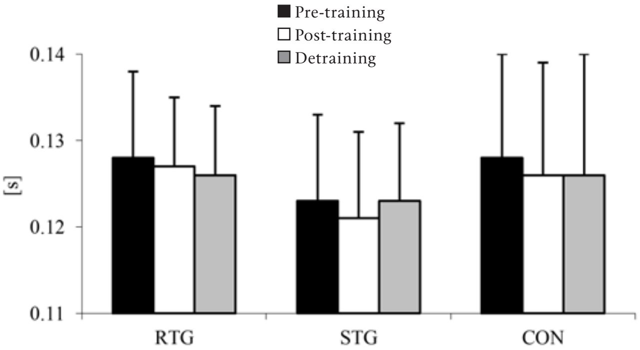
RTG – running resisted training group
STG – standard training group
CON – control group

Figure 7. Mean ± SD knee angle at footstrike measured pre-training, post-training, and three weeks after completing training (detraining)



\# – significantly different (p < 0.05) from pre-training values
RTG – running resisted training group
STG – standard training group
CON – control group

Figure 8. Mean ± SD ground contact time measured pre-training, post-training, and three weeks after completing training (detraining)



RTG – running resisted training group
STG – standard training group
CON – control group

Figure 9. Mean ± SD flight time measured pre-training, post-training, and three weeks after completing training (detraining)

length, the only significant differences were observed among the resisted training group (RTG) after completing the training program (by 5.9%; $p < 0.05$). In turn, stride frequency changed significantly ($p < 0.05$) in both experimental groups, for the RTG it decreased by 3.4%, while for the STG it increased by 3.3%. The RTG featured a significant increase in knee angle at toe off at post-training (by 2.3%; $p < 0.05$). Additionally, group RTG was the only one with a significant increase in ground contact time (by 7.2%; $p < 0.05$). For the control group none of the measured parameters changed significantly ($p > 0.05$).

Discussion

The obtained results confirm the validity of using resisted sprint training in increasing running speed. The RTG, which trained for nine weeks by pulling an external load, improved mean running speed during the acceleration phase as well as increased stride length despite a decline in stride frequency. In addition, the effects of resisted sprint training were observable even in measurements taken three weeks after completing the training program (detraining).

An improvement in running speed was also observed in the STG, suggesting that this form of training – probably due to its specificity – is also effective in improving running velocity. However, the mechanisms behind both groups' velocity improvements proved to be different. Running stride length increased only in the RTG, which is an effect that has also been confirmed by Delecluse [18] when studying resisted sprint training. It is believed that increase in stride length is the result of performing a fuller leg extension at the knee with each additional step, as evidenced by the increasing rise in the knee angle at toe off. Some researchers believe [3] that this change indicates an increase in strength among hip and knee extensor muscles. The results of this study did confirm the findings of Zafeiridis et al. [9] or Spinks et al. [10], who did not observe any change in stride length. It is worth mentioning that the differences in the results between these researchers and the present study's may stem from the use of different training techniques. Unfortunately, as is usual in scientific literature, details on the types of solutions used to monitor correct technique during movement execution are rarely provided. Therefore, if the methodology used was in fact the cause of such a discrepancy, this could be the result of ineffective controls, such as when providing instructions on extending the rear leg at the knee during toe off, this could have lead participants to perform an even larger bend at the knee than necessary, resulting in shorter stride length. Furthermore, the increase in stride length as observed in group RTG was found to be long-term, as three weeks after completing the training program (detraining) not only were there no decreases in stride length when compared with post-training values, but this parameter was still significantly higher than when measured pre-training.

Nonetheless, not all of the effects of resisted sprint training were positive, such as the decrease in stride frequency. These findings are in complete discrepancy with those by Zafeiridis et al. [9], who observed an increase in stride frequency, and by Spinks et al. [10], who observed no significant change. We believe that group STG's decrease in stride frequency may have been the result of increased stride length, and thus prolonged contact with the ground due to the larger distance that the body's center of mass needed to cross. This observation is in line with other researchers [16, 19], who confirmed that stride length and stride frequency, determined by the ground contact time as well as flight time, are antagonistic parameters. Although shortening ground contact time is highly desirable in sprinting, it should be noted that longer ground contact time (within limits) is conducive to producing more force during toe off; this is advantageous, as Weyand et al. [20] observed, since running velocity is determined to a great extent by the force developed by the legs during the stance phase and not by the speed of the legs when in flight (swing phase).

It is highly probable that the increase in stride frequency by group STG was due to shorter ground contact time, although this result was not statistically significant ($p > 0.05$). Shortened ground contact time has been linked with increased stiffness of the muscle-tendon unit, thus allowing for more efficient use of the extension-contraction cycle [21], as Markovic et al. argued [22].

It also is worth emphasizing that no changes were observed in knee angle at the moment when the foot makes contact with the ground (footstrike) in either of the experimental groups, which may indirectly indicate poor technique during the forward swing phase. We assumed that greater knee angle is equivalent to increased stride length, especially in regards to the distance between the body's center of mass and the point of footstrike. Therefore, as this distance increases so does braking force [23], which consequently carries with it an increased risk in straining the rear thigh muscles [24]. This type of injury is very common among individuals who practice speed-strength sports [25].

One of the limitations of this study, besides the small sample size and relatively short duration of the training programs, is that only the lower limbs were subjected to analysis. However, the significance of omitting the upper limbs from analysis may be minimized by taking into consideration the results of Spinks et al. [10], who found no changes in the kinematic parameters of the upper limbs after standard and resisted sprint training, emphasizing the relatively minor role the upper limbs play in improving running speed [26].

It needs to be highlighted that the implementation of a resisted sprint training program requires carefully research, especially during the competitive season, as research has shown that this form of training significantly impacts a number of kinematic parameters that form the core of running technique, such as by lowering stride frequency. Significant changes introduced during the running season may lead to instable locomotor patterns and thus adversely affect running times. On the other hand, it would be desirable for future studies to determine which solutions are suitable for developing strength, especially when beginning training with the use of resisted training. This is important in light of the findings by Moira et al. [27], who noticed a decrease in running speed and a reduction in stride frequency (increased ground contact time and flight time) as the result of strength training, where solutions based on resisted training could provide an alternative to standard strength-building exercises.

The above aspect also requires careful consideration when choosing the correct external load. We found that the weight used in this study (7.5% of body mass, but also 10%) was adequate in terms of the exercise potential of the relatively untrained, although physically active, female students. However, depending on the desired outcome, every situation requires an individual and careful assessment as to best decide the most optimal load. This includes taking into consideration not just sex, age or physical fitness level, but also the movement and functional specifics of a given sport and its requirements as to speed.

Conclusions

1. The results of the present study indicate that resisted sprint training in women, by pulling an external load, improves short-distance running velocity.

2. Resisted sprint training led to increases in stride length and completing fuller leg extensions at the knee joint during toe off but, concomitantly, caused an decrease in stride frequency and increase in ground contact time. Standard sprint training was found to increase

stride frequency, without any significant changes in stride length.

3. The long-term effects of the sprint training programs (resisted and standard) used in present study were similar for both experimental groups. The three-week detraining period following the completion of the training programs had no significant effect on any of the running gait parameters.

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