THE CENTRIFUGAL TRACK AS A TOOL FOR SPRINT-SPECIFIC STRENGTH TRAINING

INTRODUCTION

A basic principle of training methodology is that of transferring muscle strength to sport-specific performance. This is typically carried out by using exercises that closely reproduce or even mimic the competition task [1]. When considering sprint running, performance-specific strength training may be achieved by means of external resistances applied to the athlete during running. This is typically referred to as “resisted sprint running” and it is a common training method for improving sprint-specific strength.

Resisted sprint running techniques include uphill running, weighted sled or parachute towing, running with a weighted belt or vest [2-6]. Generally, sled towing is usually preferred to parachute since it benefits of being relatively unaffected by wind. Moreover, the amount of overload when training with air-based resistance devices is not easily standardizable. Conversely, overloads should be assigned in percentage of the subject’s body mass [7-9]. Weighted sled and vest/belt well satisfy, instead, this requirement. Finally, a weighted belt should be preferred to the vest in order to minimize the torque about the hips that is usually related to an increase of forward trunk lean (i.e., trunk flexion).

If it has been said that resisted sprint running techniques are useful for increasing muscular force output that potentially lead to an increase in stride length [2, 10-13]. On the other hand, several authors have argued that towing will not benefit sprint performance for it may have detrimental effects on the athlete’s posture during running [3, 5, 13-15]. For this reason, several researchers analyzed the postural alterations caused by uphill running [16], sled towing [8, 9, 17], parachute towing [9] and weighted belt [9].

Excluding uphill running [16], where a 3° slope caused significant increase of trunk flexion and decrease in knee range of motion (ROM) that lead authors to reject the hypothesis that posture would remain unchanged, the general idea that sled training yields to kinematics disruption can be generally rejected for two main reasons [1]. First, postural alterations and other significant kinematic changes depend on the magnitude of the applied resistance and can be, thus, avoided with a proper load assignment and periodization in the athlete’s training program. Second, a better awareness on the potential benefits/non benefits of resisted sprint training techniques is still missing due to the lack of longitudinal studies to assess chronic changes induced by such a training typology.

With regard to the first argumentation, it has been proven that the use of a relatively light load, such as the 12.5% of body mass, provides a training stimulus without inducing detrimental changes in sprinting technique [8]. Some significant changes, such as an increased knee extension at takeoff, resulted to be even profitable for improving sprint running performance. Similarly, the increased trunk flexion that was found by authors may be considered suitable as well for its specificity to the acceleration phase of sprint running. Infact, the only longitudinal study on the effects of 8-weeks of sled towing on sprint performance revealed a significant 2% gain in running velocity over the first 20m without improvement in maximum speed [17]. Nevertheless, it has to be pointed out that the acceleration phase and the maximum velocity phase are related to different and specific qualities. In other words, training the acceleration phase does not necessarily have a positive effect on the maximum velocity phase. Finally, a recent study that analyzed the kinematics of three different types of resistance (sled, parachute and weighted belt) did not even observe any significant changes in posture when sled towing or running with a weighted belt with a 16% and 9% of body mass, respectively [9].

Generally, kinematic alterations depends on the type of resistance: weighted belt/vest produce a vertical force applied to the trunk/waist and directed downward, a parachute will produce a horizontal force localized to the waist and directed posteriorly, whereas a weighted sled will produce a force localized to the waist and directed postero-downward towards the direction of the cord. For this reason, towing a sled or a parachute will likely produce a trunk flexion, while a weighted belt will likely not affect the athlete’s posture during running since the force has the same direction and verse of the weight of the athlete.

Beyond the fact that conventional resisted sprint techniques may disrupt, positively alter or not alter at all the athlete's posture during running, the fact remains that the overload produced by such devices is localized and it cannot be increased for the sake of the athlete's postural integrity. Generally, any localized overload is never a good thing for the musculoskeletal system and it may lead, with time, to overuse injuries. The present study aims to analyze running on a "centrifugal track" as an alternative technique for sprint-specific strength training [18]. The centrifugal track consists in a basin-shaped track characterized by a platform with a parabolic section. It can be assumed as composed of consecutive rings of increasing radius. The inclination of the platform with respect to the horizontal axis increases from the bottom to the top as the radius increases. This particular track exploits the centripetal acceleration to increase the weight of the subject during the stance phase: while running, the athlete has to change direction at every support phase to maintain a circular trajectory, giving rise to a centripetal acceleration which is added to gravity resulting in an equally-distributed (rather than localized) "overweight" of the athlete. A closed mathematical relationship exists between radius (incline), velocity and overweight The overload can be modulated by running with a higher velocity on a higher, more inclined, ring of the platform to increase the centripetal acceleration. Conversely to running on flat curves, that also gives rise to a centripetal acceleration but it is also characterized by an inclined longitudinal axis of the athlete, in this case it is the platform to be inclined. The longitudinal axis of the athlete is, thus, perpendicular to the platform (as if the subject run straight) as long as the athlete runs with that specific velocity related to the radius/incline of the platform's ring on which he is running. For this reason, no postural changes are expected from the analysis of this running typology.

METHODS

The centrifugal track

The model of centrifugal track analyzed in the present study was characterized by a radius ranging from 2.5 m to 3.5 m. The track was characterized by five visible lanes (rings), with different incline, as a visible reference on which the athlete is asked to run on in order to exploit a specific overload (Fig. 1).

Figure 1. The centrifugal track analyzed in the present study.

The dynamic of running on the centrifugal track is governed by the following law:

$$R = m(g\cos\alpha + \frac{v^2}{r}\sin\alpha) \qquad \text{(eq. 1)}$$

where "R" is the component of the ground reaction force along the longitudinal axis of the athlete, "g" is the gravitational acceleration, "m" the mass of the subject, "r" the radius of the lane, "α" the incline of the platform and "v" the average progression velocity of the athlete's centre of mass (CM) during the stance phase.

$\frac{v^2}{r}$ is the centripetal acceleration of the athlete's CM. From eq. 1, a closed mathematical relationship results between the radius, the incline, the velocity and overweight (Fig. 2).

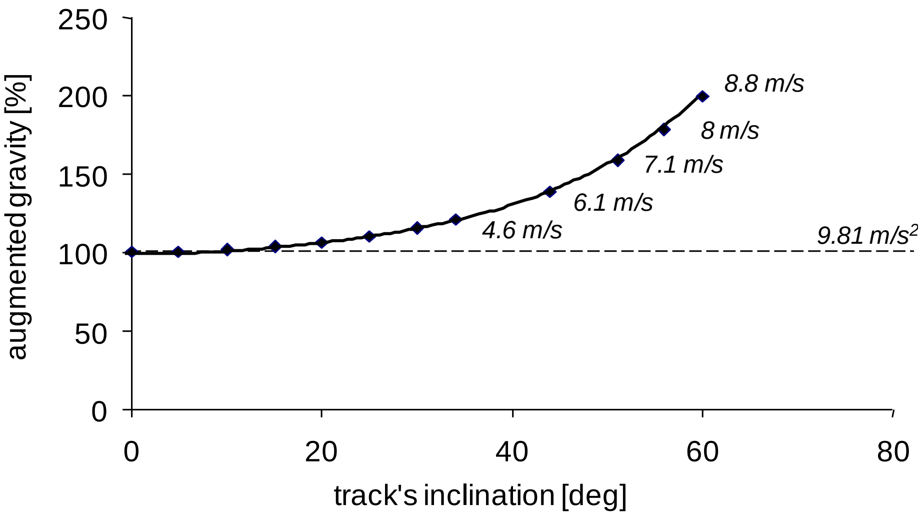

Figure 2. Graphical representation of the law governing the dynamics of running on the centrifugal track.

The term of eq. 1 in brackets can be considered as the increased acceleration that, multiplied by the mass of the subject, resulted in the apparent “overweight” of the athlete. At each incline, there is a specific velocity so that the athlete experiences the overweight while his longitudinal axis is orthogonal to the contact area (Fig. 3). It has to be stressed that the overload manifests solely during the stance phase since the centripetal acceleration rise from friction. During the flight phase the athlete is subjected solely to the Earth’s gravitational force.

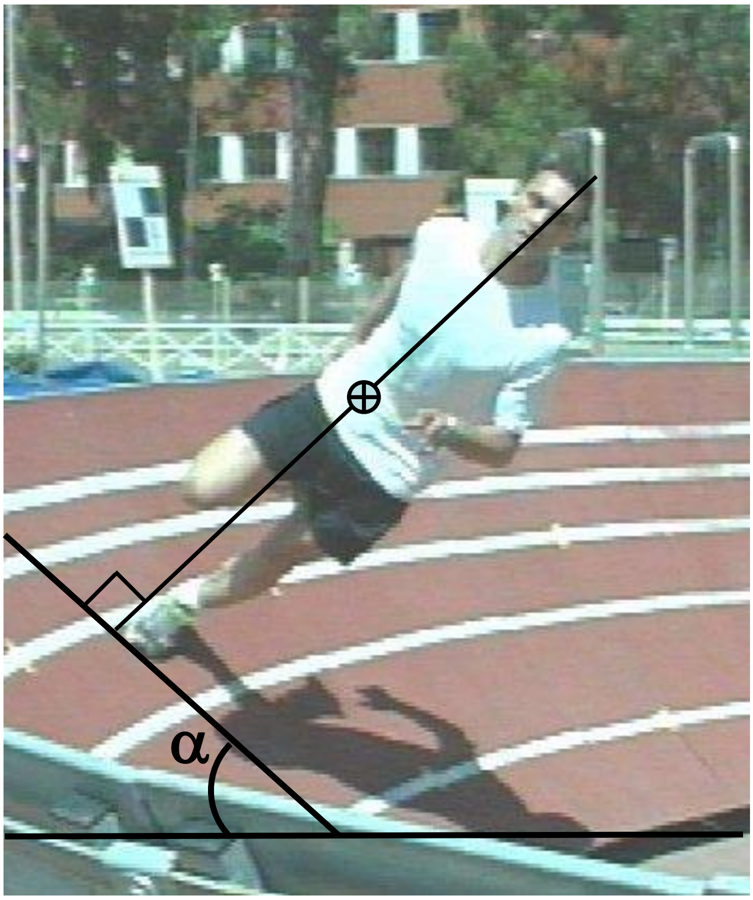

Figure 3. The longitudinal axis of the athlete is perpendicular to the running lane (as he run straight) as long as the speed velocity is that related to the radius of the lane.

Experimental approach to the problem

The study was conducted on 4 male amateur sprinters (age=21±3 yrs; mass=72±5 kg; stature=174±4 cm) who were exposed to 2 month (2 days/week) of familiarization with the centrifugal track prior to perform the test. Athletes were free to chose the most comfortable running lane and verse for the test. The latter consisted in completing three laps. All subjects run anticlockwise (the right side of the body was the outer side) on the 2° lane, characterized by an incline of 44°, a progression velocity of 6.1 m/s and a theoretical overweight of 1.5 bodyweight (Fig. 2). A complete stride of the last lap was filmed by two fixed cameras at 50 frames per second (50 Hz of sampling frequency) and used for a three-dimensional (3D), video-based, kinematical analysis of running. A custom software was used for calibrating the cameras and for manually digitizing, for any given frame, the position of 21 landmarks on the subject's body (Fig. 4).

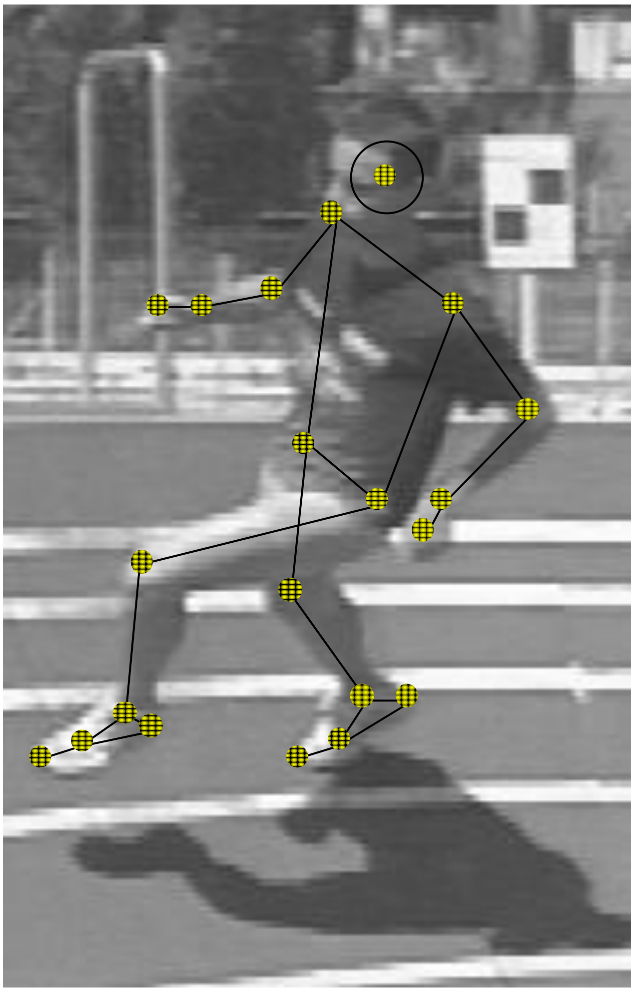

Figure 4. The 21-points biomechanical model.

All digitizing was performed by the same operator to maximize the consistency in the identification of body landmarks. The position of a landmark in space is identified by the intersection of the two lines of sight of each camera. Often these two lines do not intersect, so the point that minimizes the distance between the two lines of sight is taken. Such distance can be considered as representative of the measurement error (i.e., spatial accuracy) and in the present study it was quantified as 15 millimeters. A 3D model of the subject during running was, hence, obtained (Fig. 5). 3D coordinates of landmarks were smoothed using a 2nd order Butterworth digital filter with a cut-off frequency of 6 Hz. Inertial parameters of each body segment were assigned according to De Leva [19] so that the position of the subject's CM could be defined in any given frame. The same analysis was performed during running on a flat track. For the latter, subjects were asked to run at approximately the same speed chosen during running on the centrifugal track. A complete stride during the steady-state phase was considered for further analysis.

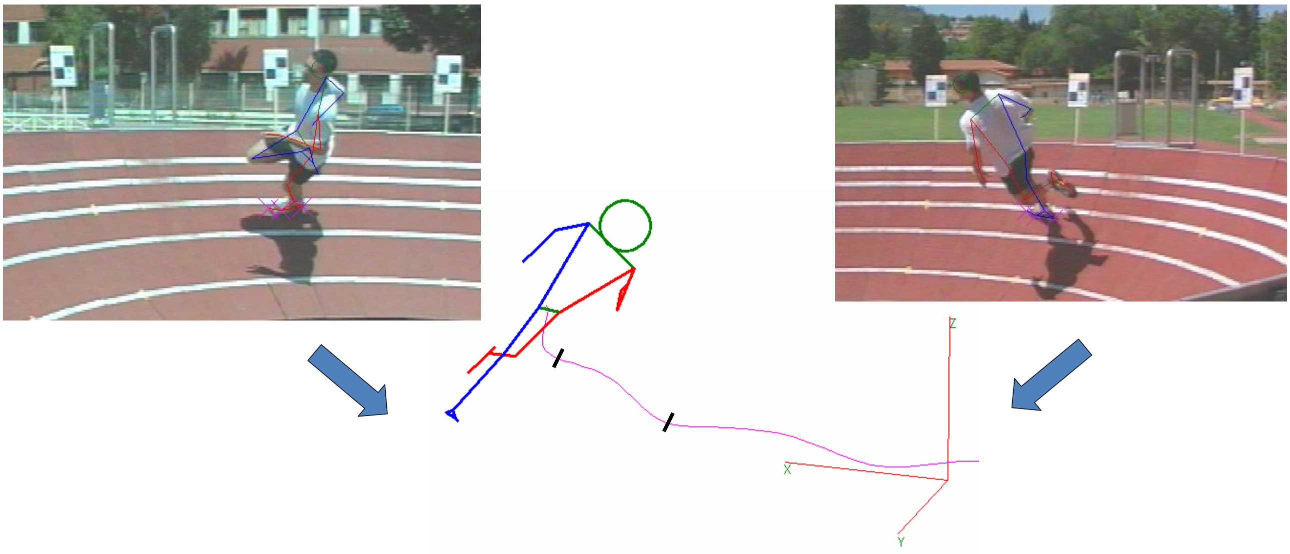

Figure 5. The 3D model of running as reconstructed from two points of view. The trajectory of the 3D position of the athlete's centre of mass is also shown (in magenta).

Data analysis

Data analysis has been designed in order to verify the common opinion that some Italian athletic coaches and trainers have about the centrifugal track: "This type of running hurts because running is not symmetrical. The inner side of the body has different spatio-temporal parameters and kinematics of the outer side. Moreover, the athlete runs in circle so running kinematics is different from flat track running". Of course, this thought has never been scientifically demonstrated but it is what has been spread from mouth to mouth throughout the past 22 years from the time when the centrifugal track was first introduced in 1994 [18].

1) between-side symmetry of running on the centrifugal track was assessed by analyzing:

   a. average inclination, on the subject's frontal plane, of the subject's longitudinal axis with respect to the vertical axis during the stance phase: this inclination has to result approximately equal to the inclination of the chosen running lane;
   b. flight duration, stance duration, step duration, step rate and step length, knee flexion at foot-strike, at mid-stance and at foot-off: no differences between right and left side are expected;

2) postural alteration of running on the centrifugal track were assessed by analyzing:

   a. trunk flexion at foot-strike and at foot-off in both running typologies: no differences between the two running typologies are expected;
   b. flight duration, stance duration, step duration, step rate and step length, knee flexion at foot-strike, at mid-stance and at foot-off: no differences between the two running typologies are expected;

3) training effect:

   a. positive external mechanical work performed by muscle forces (computed as the variations of the total mechanical energy associated to the subject's CM from mid-stance to foot-off): a higher external mechanical work during running on the centrifugal track is expected with respect to flat track running;

Temporal parameters were measured by visual inspection of the movies (note that the temporal resolution was imposed by cameras sampling frequency and limited to 0.02 s. Step length ad running velocity were estimated according to Mero and Komi [20]. Angular convention for trunk and knee flexion is showed in Figure 6. The total mechanical energy of the CM was computed by summing the potential ad kinetic energy of CM [21]. Instantaneous velocity of the CM, required for computing the kinetic energy associated to the CM, was computed by a spline-mediated numerical differentiation method as suggested by [22].

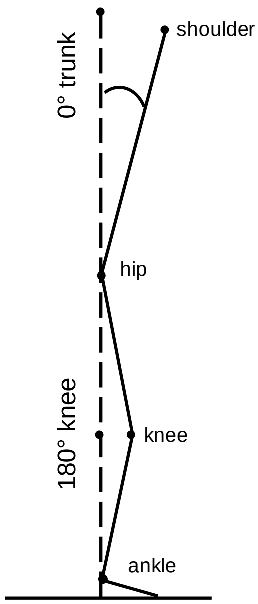

Figure 6. Angular convention used for expressing trunk and knee kinematics.

Statistical analysis

The independent variables for point 1.b were the left and right side (right side, R, and left side, L), whereas the independent variables for point 2.b were the two running conditions (centrifugal track, CT, and flat track running, FT). The dependant variables for both point 1.b and 2.b were the angular kinematic quantities (trunk and knee kinematics) and the spatio-temporal parameters related to the single step (duration, stance duration, step duration, step rate and step length). Angular kinematics used for comparison was that related to the instants of foot-strike, mid-stance and foot-off according to what has been previously done in similar studies [16, 9]. Differences between the two running typologies for any considered depend variable is expressed as the difference of flat track running with respect to the centrifugal track (CT-FT). Similarly, differences between right and left side is expressed as the difference of the left side with respect to the right side (R-L). Statistical differences were assessed using a paired t-test. The level of significance was set to $p<0.05$.

RESULTS

Running speed was 6.6±1.3 m/s and 6±0.5 m/s for FT running and running on the CT, respectively. Hypothesis 1.a was accepted since the average inclination of the athlete's longitudinal axis on the subject's frontal plane during stance was approximately ranged from 42° to 46° (incline of the platform relative to the running lane was 44°). Hypothesis 1.b was accepted since no significant differences were found between the spatio-temporal parameters and knee kinematics of the right and left leg during running on the centrifugal track (see Table 1.b, Table 2 and Table 3). Hypothesis 2.a was accepted since no significant differences were found between CT and LV in terms of trunk flexion at foot-strike and at foot-off (see Table 4). Hypothesis 2.b was partially accepted: no significant differences were found between CT and LV in terms of spatio-temporal parameters and knee kinematics at foot-strike, while small (~5%) but significant increase of knee extension was found at mid-stance and foot-off (see Table 1.b, Table 2 and Table 3). Finally, hypothesis 3.a was accepted since the positive mechanical work during CT running was found, on average, 24% significantly greater with respect to FT running.

Table 1.a: temporal parameters relative to flat track (FT) running both for right (R) and left (L) step.

FT run	**stance duration [s]**		**flight duration [s]**		**step duration [s]**	
side	R	L	R	L	R	L
mean (sd)	0.135 (0.01)	0.135 (0.01)	0.14 (0.016)	0.14 (0.016)	0.275 (0.019)	0.275 (0.019)

Table 1.b: temporal parameters relative to running on the centrifugal track (CT) both for right (R) and left (L) step. Between-side and between-track percentage differences are reported (* identifies a statistical difference).

CT run	**stance duration [s]**		**flight duration [s]**		**step duration [s]**	
side	R	L	R	L	R	L
mean (sd)	0.17 (0.012)	0.17 (0.012)	0.1 (0.016)	0.1 (0.016)	0.27 (0.02)	0.27 (0.02)
% R-L	0		0		0	
% CT-LR	20.6*		-40*		-1.9	

Table 2.a: step length relative to running on the centrifugal track (CT) and on flat track (FT) both for right (R) and left (L) step. Between-side and between-track percentage differences are reported (* identifies a statistical difference).

step length [m]	CT run		LR run	
side	R	L	R	L
mean (sd)	1.62 (0.05)	1.58 (0.05)	1.8 (0.29)	1.91 (0.24)
% R-L	2.5			
% CT-LR	-11.6			

Table 2.b: step rate relative to running on the centrifugal track (CT) and on flat track (FT) both for right (R) and left (L) step. Between-side and between-track percentage differences are reported (* identifies a statistical difference).

step rate [Hz]	CT run		LR run	
side	R	L	R	L
mean (sd)	3.7 (0.3)	3.7 (0.3)	3.6 (0.2)	3.6 (0.2)
% R-L	0			
% CT-LR	1.9			

Table 3: knee kinematics during running on the centrifugal track (CT) and on flat track (FT) both for right (R) and left (L) step. Knee kinematics is reported at foot-strike, at mid-stance and at foot-off. Between-side and between-track percentage differences are reported (* identifies a statistical difference).

knee angle [deg]	foot-strike				mid-stance				foot-off			
side	R		L		R		L		R		L	
running typol.	CT	FT	CT	FT	CT	FT	CT	FT	CT	FT	CT	FT
mean (sd)	155 (4)	154 (6)	156 (3)	153 (4)	146 (3)	138 (4)	144 (2)	138 (4)	166 (6)	158 (6)	165 (2)	154 (3)
% R-L	-0.4				1.4				0.9			
% CT-LR	0.6				5.3*				5.1*			

Table 4: trunk kinematics during running on the centrifugal track (CT) and on flat track (FT) both for right (R) and left (L) step. Trunk kinematics is reported at foot-strike and at foot-off. Between-track percentage differences are reported (* identifies a statistical difference).

trunk flexion [deg]	foot-strike		foot-off	
running typol.	CT	FT	CT	FT
mean (sd)	30 (0)	27 (2)	37 (1)	37 (4)
% CT-LR	8		1.2	

DISCUSSION

The present study aimed to propose the centrifugal track as a sprint-specific strength training tool able to increase training loads without disrupting normal running kinematics. This purpose was carried out comparing the kinematics of running on the centrifugal track with respect to flat track running at similar speed. Flat track running speed was found 9% higher than running on the centrifugal track but not statistically different. Running speed recorded on the centrifugal track was equal to the theoretical velocity expected on the running lane chosen by athletes.

Training effect was proven by a significantly greater positive mechanical work performed by muscle forces during running on the centrifugal track with respect to flat track running despite the similar running speed. The overload originates from the centripetal acceleration that rises from friction and allows the athletes to change direction at every stance phase and follow the circular trajectory of the lane. This happens only during the stance phase. During the flight phase, the athlete's CM is, indeed, subjected solely to the gravitational force and its trajectory is parabolic and occurs on the subject's sagittal plane as it normally happens during normal running (Fig. 5 and 7).

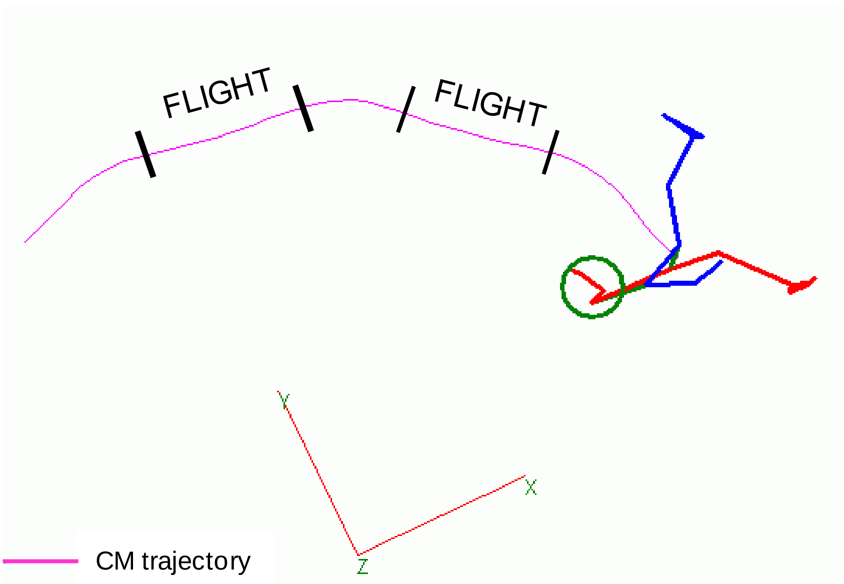

Figure 7. Transverse view o running on the centrifugal track. From the athlete's CM trajectory it is clear the change of direction during the stance phase. The flight is unchanged : CM's trajectory is straight and occurs on the subject sagittal plane (see Fig. 5).

Common-opinion conjectures related to asymmetric running were all rejected. First, the longitudinal axis of the athletes was proved to be perpendicular to the running lane. Second, no significant changes were found in spatio-temporal parameters and knee kinematics between the right (outer) and the left (inner) leg.

With respect to flat track running, previous studies found that towing a weighted sled reduces the athlete's step length, step rate and flight duration and increases the ground contact time. Excluding step rate and step length, for which no significant differences were found between running typologies, the present study found as well a significant decrease of flight duration and a significant increase of stance duration. This because of the higher load to which the athlete is exposed. Interesting is the fact that the step duration (sum of stance and flight duration) was found almost equal and not statistically different between the two running typologies. Also interesting is the relatively high decrease (-11%) of step length on the centrifugal track that, however, was not found to be significant.

As for sled towing, a positive effect on knee kinematics was found during running on the centrifugal track: a significantly greater knee extension was found at foot-off with respect to flat track running. This may indicate that the athlete is attempting to gain an increase in propulsive force through a more vigorous knee extension of the shank segment. It has been suggested, indeed, that a full extension of the lower limbs is a key factor in sprint performance [23-25].

With regard to trunk configuration, conversely to uphill running [16] and sled towing [8, 9] and similarly to running with a weighted belt [9], trunk flexion during running on the centrifugal track was not altered both at foot-strike and at take-off. As it has been suggested that an increased trunk flexion may be profitable for its specificity with the acceleration phase of sprint [1, 17], the unaltered trunk flexion during running on the centrifugal track might lead to assume the centrifugal track as specific for the maximum speed phase of sprint.

A limitation of the present study was the sampling frequency of cameras that led to a low temporal resolution of 0.02 s. This might has “flattened” the estimation of stance and flight duration that have usually variations in the order of milliseconds. On the other hand, it has to be noted that this sampling frequency was also adopted by another similar study that compared unloaded and resisted sprint running [9]. Finally, a further limitation can be considered the fact that speed on flat track was superimposed. In the present study, researchers asked the athletes to fulfill the hard task to run with a similar speed to that recorded during running on the centrifugal track This was done for the sake of comparisons but, at the same time, with the risk of altering the normal running kinematics because speed was controlled. A further research might be based on comparing running at maximum velocity on both flat and centrifugal track. This solution has been adopted by a similar study comparing unloaded and resisted sprint running [9]. Running at maximum speed on the centrifugal track requires, though, a very good level of familiarization with this type of running. This because the athlete cannot arbitrarily choose to run on a higher lane until he becomes able to run at a higher velocity. This requires the ability to sustain a higher load that can be only fulfilled with training.

CONCLUSION

The centrifugal track has proven to be a valid alternative to common resisted sprint running techniques for sprint-specific strength training. Contrary to common resisted sprint running, running on a centrifugal track showed to provide a training effect without localized overloads on the musuloskeletal system and detrimental postural changes. Furthermore, conversely to sled towing, the centrifugal track allows to increase the overload without necessarily disrupting running kinematics. Longitudinal studies are needed to prove the benefits of the centrifugal track on sprint performance. Strength and conditioning researchers should also focus on the definition of ad-hoc training programs that may standardize the use and periodization of such a sprint-specific strength training tool.

RECOMMENDATIONS

The centrifugal track was first introduced by his inventor, an Italian engineer, in 1994. Since then, the number of centrifugal tracks mounted on the Italian territory can be still counted with two hands. In 22 years, the Italian Athletics Federation has never really showed any interest in this and it never promoted a research to clarify the characteristics of running on such a track. The common opinion of some Italian athletics coaches and trainers is that “running on the centrifugal tracks hurts”. This probably because some of their athletes or themselves tried to run inexpertly on a centrifugal track without any ruled approach or familiarization protocol. Or perhaps just because the invention did not came from their circle (but this falls into the “Italian style”). Therefore, a first recommendation we feel to give to coaches is not to hear these unfounded opinions but to critically read scientific literature instead. The second recommendation is more practical: guide your athletes through a proper period of familiarization with the centrifugal track before to start a proper strength training program. Those few athletes who used the centrifugal track refer to have dramatically reduced their personal bests. A centrifugal track was recently incorporated into an outdoor training park (the Athletics Exploratorium) of the University of Southern Denmark in Odense.

REFERENCES

2. Young WB. Transfer of strength and power training to sports performance. Int J Sports Physiol Perform. 2006 Jun;1(2):74-83.
3. Faccioni, A. Assisted and resisted methods for speed development: Part 2. Mod Athlete Coach 32: 8–12, 1994.
4. Jakalski, K. Parachutes, tubing, and towing. Track Coach 144: 4585–4589, 4612, 1998.
5. Sheppard, J. The use of resisted and assisted training methods for speed development: coaching considerations. Mod Athlete Coach 42: 9–13, 2004.
6. Tabachnik, B. The speed chute. NSCA J 14: 75–80, 1992.
7. Young, W, Benton, D, Duthie, G, and Pryor, J. Resistance training for short sprints and maximum-speed sprints. Strength Cond J 23: 7–13, 2001.
8. Bosco, C, Rusco, H, and Hirvonen, J. The effect of extra-load conditioning on muscle performance in thletes. Med Sci Sports Exerc 18: 415–419, 1986.
9. Lockie RG, Murphy AJ, Spinks CD. Effects of resisted sled towing on sprint kinematics in fi eld-sport athletes. J Strength Cond Res. 2003;17(4):760-767.
10. Alcaraz PE1, Palao JM, Elvira JL, Linthorne NP. Effects of three types of resisted sprint training devices on the kinematics of sprinting at maximum velocity. J Strength Cond Res. 2008 May;22(3):890-7.
11. Artingstall, R. Strength without weights (part II). Rugby 16:23. 1990.
12. Costello, F. Training for speed using resisted and assisted methods. NSCA J. 7:74–75. 1985.
13. Donati, A. The association between the development of strength and speed. N. Stud. Athlet. 11:51–58. 1996.
14. Pauletto, B. Speed-power training: How to get that last 10% effort to assure a good speed workout. Scholastic Coach 63:54–55. 1993.
15. Lavrienko, A., J. Kravtsev, Z. Petrova. Non-traditional training. Modern Athlete and Coach 28:3–5. 1990.
16. Pauletto, B. The speed chute. NSCA J. 13:47–48. 1991.
17. Paradisis G. P., Cooke C. B., Kinematic and postural characteristics of sprint running on sloping surface, J. Sport Sci., 2001, 19:149-159.
18. Zafeiridis A, Saraslanidis P, Manou V, Ioakimidis P, Dipla K, Kellis S. The effects of resisted sled-pulling sprint training on acceleration and maximum speed performance. J Sports Med Phys Fitness. 2005;45:284-290.

19. Scuderi G., Pista centrifuga, Tecnica e Ricostruzione, XLIX (2), 1994, p. 24-29.

20. De Leva P., Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters, Journal of Biomechanics, 1996, 29(9):1223-1230.

21. Mero, A. and Komi, P. (1985). Effects of supramaximal velocity on biomechanical variables in sprinting. International Journal of Sport Biomechanics, 1, 240–252.

22. Cavagna G., Thys H., Zamboni A., The sources of external work in level walking and running, Journal of Physiology, 1976, Nov., 262(3): 639-57.

23. Woltring HJ. On optimal smoothing and derivative estimation from noisy displacement data in biomechanics. Human Movement Sci; 1985; 4:229–245.

24. Adelaar, R.S. The practical biomechanics of running. Am. J. Sport Med. 14:497–500. 1986.

25. Korchemny, R. A new concept for sprint start and acceleration training. N. Stud. Athlet. 7:65–72. 1992.

26. Van Ingen Schenau, G.J., De Konij J.J., De Groot. Optimisation of sprinting performance in running, cycling and speed skating. Sports Med. 17:259–275. 1994.