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The Influence of Applied Blood Flow Restriction Cuffs on Kinematics of Submaximal Sprinting

Ryu Nagahara [1,*] and **Takashi Abe** [2]

[1] National Institute of Fitness and Sports in Kanoya, 1 Shiromizu-cho, Kanoya 891-2393, Japan
[2] Department of Health, Exercise Science, & Recreation Management, The University of Mississippi, 224 Turner Center, University, MS 38677, USA; t12abe@gmail.com
* Correspondence: nagahara@nifs-k.ac.jp; Tel.: +81-994-46-5034

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Abstract: It is unknown how sports activity combined with blood flow restriction (BFR) on the limbs can impact the exercising limb's motion. We aimed to compare the lower limb kinematics between submaximal sprinting with and without BFR cuffs (i.e., BFR and normal conditions) when they were applied on the upper thigh. Ten collegiate sprinters performed five 45-m submaximal sprint trials under normal and BFR conditions. The BFR was applied to both legs at the proximal portion of the thigh utilizing elastic cuffs. The cuff pressure was set at approximately 60% of estimated arterial occlusion pressure. Spatiotemporal and hip and knee joint kinematic variables for both legs during submaximal sprinting were obtained using a motion capture system. The results showed, for spatiotemporal variables, no significant difference ($p > 0.653$), a trivial or small effect size (0.050–0.205), and high correlation coefficients ($r > 0.923$) between conditions. Moreover, for the joint angles and angular velocities, no significant difference ($p > 0.244$) and a trivial or small effect size (0.003–0.538), as well as significant correlations ($r > 0.684$) were found between conditions. These results indicate that, in general, there is probably no influence of BFR cuffs on the upper thigh on running kinematics.

Keywords: training; strength; performance; biomechanics; physiology

1. Introduction

During the past two decades, a large number of studies have been published investigating the efficacy of acute and chronic low-intensity exercise combined with blood flow restriction (BFR) [1–3]. Several studies revealed that low-load resistance training with BFR could elicit similar muscle hypertrophy and strength gains as traditional high-load resistance training [4–6]. It has also been reported that the BFR stimulus facilitates low-intensity aerobic exercise-induced muscle adaptations [7–9]. In addition, short-term low-intensity interval training with BFR improves both maximal oxygen uptake and muscular strength [10].

Recently, one study investigated the effects of submaximal (60–70% of maximal 100-m sprinting speed) sprint training with and without BFR on 100-m sprint performance in male sport university students [11]. The authors reported that 100-m sprint time was improved by submaximal sprint training with BFR on the lower limbs, but not by submaximal sprint training without BFR. This is an interesting new topic and the first study to examine the effects of BFR on sports performance when applied during the same sports activity. From a biomechanical standpoint, however, the study raises a potential concern about the influence of applied BFR cuffs on the lower limb kinematics during submaximal sprinting. This is therefore important to consider, because a restriction of motion can impair sports activity techniques, and it is unknown whether submaximal sprinting with BFR on the lower limbs affects their motion. In previous studies, elastic taping on the lower limb did not affect limb function, knee extensor peak torque, or electromyographic activity of the vastus lateralis [12], but inelastic taping on the ankle restricted its range of motion during running [13]. Although these studies did not use BFR cuffs, these findings would suggest that the BFR cuffs may potentially restrict lower limb motion when the cuffs are fastened tightly on the lower limbs.

The purpose of this study was to compare the lower limb kinematics between submaximal sprinting with and without BFR cuffs when they were applied on the upper thigh of collegiate sprinters. We hypothesized that the influence of applied BFR cuffs on lower limb kinematics during submaximal sprinting would be negligible when a moderate cuff pressure was used. It could be beneficial to evaluate the influence of BFR on the upper thigh under the actual sub-maximal running condition that some athletes and coaches may use as part of a rehabilitation or training program.

2. Materials and Methods

Nine male and one female collegiate sprinters (in total 10) volunteered for this study (mean ± s.d.: age, 20.4 ± 0.8 year; stature, 1.73 ± 0.05 m; body mass, 65.4 ± 5.9 kg; personal best 100-m race time, 11.46 ± 0.65 s). All participants gave written informed consent before the experiment. The research ethics committee of the National Institute of Fitness and Sports in Kanoya approved the experimental procedures beforehand (#3-55, 2016).

After warming up, the participants performed five 45-m submaximal sprint trials from a standing position under normal and BFR conditions at running speeds of 75–85% of the average speed of their best record of the 100-m race. A previous study reported that sprinting performance was improved by submaximal (60–70% of the maximal speed in the 100-m sprint) sprint training with BFR [11]. Based on the relationship between average and maximal running speeds in the 100-m race (e.g., 10 m/s on average and 11.2 m/s at the maximum) [14], 75–85% of the average speed of their best record of the 100-m race can be considered as 67–76% of the maximal speed. While the range of running speeds in our study was slightly higher than that in the previous study [11], the participants (sprinters) in this study comfortably performed submaximal sprinting at 75–85% of the average speed of their best record of the 100-m race rather than the lower speed range based on the pilot test. Thus, we adopted these speeds as the target range.

The trials were performed in a randomized order. Between trials, participants rested for at least 3 min. We measured the time for 10-m from the 35-m mark using a photocell system (TC Timing System, Brower, Draper, UT, USA). Just after each trial, we fed back the 10-m time to the participant to adjust running speed to be in the target range. When the participant could not run within the target speeds, he/she was requested to run again until five successful trials were collected for each of normal and BFR conditions (actual trial numbers being 11 to 18 in total). When the trials exceeded five in each condition, the participants rested for 5 to 10 min to ensure their full recovery. BFR was applied to the proximal portion of the thigh utilizing elastic cuffs (5-cm width) for both legs. The cuff pressure was set at approximately 160 mmHg (±5 mmHg). Prior to the experiment, we estimated the thigh arterial occlusion pressure using a previously reported prediction equation [15], and the mean arterial occlusion pressure (n = 10) was 265, s.d. = 12 mmHg. In addition, different material cuffs (elastic vs. nylon) of the same width had similar arterial occlusion pressures [16]. In the present study, we used a moderate cuff pressure (approximately 60% of estimated arterial occlusion pressure) even though similar training adaptations have been observed between 40% and 90% of arterial occlusion pressure [17].

Sixteen infrared cameras (Raptor-E, Motion Analysis Corporation, Santa Rosa, CA, USA; 250 Hz) captured three-dimensional coordinates of 40 retro-reflective markers affixed to the participant's body from the 36-m mark with a volume (length × width × height) of approximately 8.5 m × 1.5 m × 2 m (Original marker coordinate data are available from Supplementary Materials section). Segment endpoints were calculated from the coordinates of the markers according to a 14-segment body model consisting of hands, forearms, upper arms, feet, shanks, thighs, head, and trunk according to a previous study [18]. Endpoints were estimated depending on the joint or body segment in question. Markers affixed to the vertex, right and left of the third metacarpal heads of dorsal hands, tops of the acromions, toes, and posterior of calcaneuses were considered as endpoints of the segments. The midpoints of the markers affixed to the styloid processes of ulnas and radii, medial and lateral epicondyles of the humeruses, malleoli, and femoral condyles were taken as the joint centers of the wrists, elbows, ankles, and knees, respectively. The midpoint of the markers affixed to the anterior and posterior parts of the suprasternal notch was considered as the proximal endpoint of the head. The hip joint center was defined as the point located 18% of the distance between the right and left great trochanters medially from the point located at one-third of the distance from the greater trochanter to the anterior superior iliac spine. The midpoint of the two hip joint centers was taken as the distal endpoint of the trunk.

The segment endpoint coordinates from approximately 10 frames before to 10 frames after the duration from the left leg foot strike (FS) to the next left leg FS (one stride) were extracted and low-pass filtered at 20 Hz. Because the lower limb segment motions during running can be assumed to be performed in the sagittal plane, we reconstructed the data to two dimensions in the sagittal plane in reference to previous studies [19,20]. Then, the position of the whole-body center of gravity (CG) was calculated using body segment parameters of Japanese athletes [21]. The velocities of CG were computed by differentiating the estimated CG positions with respect to time.

FS and toe-off (TO) instants were determined using a previously proposed kinematic data-based method [22]. Running speed was calculated as mean CG velocity during one step. Step frequency was calculated as the inverse of a step duration. Step length was calculated as the anterior–posterior distance of CG travelled during one step. Support and flight times were the durations between consecutive FS and TO and TO and FS, respectively. All spatiotemporal variables of right and left leg steps were averaged. For lower limb kinematic variables, support leg hip and knee joint angles and angular velocities at FS and TO were obtained for both legs. The hip joint was the relative angle of the trunk and thigh (anterior side). The trunk was determined as a segment from the midpoint of hip joints to the proximal endpoint of the head. The knee joint was the relative angles of the thigh and shank (posterior side). Moreover, hip and knee maximum extension and flexion angles and angular velocities during one stride cycle from FS to the next FS of the left leg were extracted for both legs. For all the variables, a mean value of five trials (except for the trials in the normal condition of two participants) for each participant in each of the normal and BFR conditions was used. Because a marker was disengaged from the participant's body in the measurement volume of the motion capture system, one trial in the normal condition for two participants was eliminated. Thus, for those participants in the normal condition, the mean value of four trials was calculated.

Means and standard deviations of respective variables of the two conditions and the difference in values between the two conditions were calculated. To compare the variables between normal and BFR conditions, a paired *t*-test was performed. Cohen's d was used as an effect size (ES) of the difference in each variable between the two conditions [23]. Threshold values for the interpretation of the ES were <0.2 (trivial), 0.2– <0.6 (small), 0.6–1.2 (moderate), and >1.2 (large) [24]. Moreover, correlation coefficients between values of the two conditions were computed to test the relationship. For the lower limb kinematic variables, statistical tests were performed with right and left legs separately. All statistical values except for Cohen's d were calculated using JMP 12 statistical software (SAS Institute Japan Ltd., Tokyo, Japan). Cohen's d was calculated as the mean difference divided by the pooled standard deviation. The significance level was set at $p < 0.05$.

3. Results

For the spatiotemporal variables, no significant difference in variables ($p > 0.653$), trivial or small ES (0.050–0.205), and high correlation coefficients ($r > 0.923$) were found between the normal and BFR conditions (Table 1). For the joint angles and angular velocities at FS and TO, no significant difference in variables ($p > 0.244$) was found between the normal and BFR conditions (Table 2). Moreover, those variables showed trivial or small ES (0.030–0.538) and significant correlations between the two conditions ($r > 0.788$). The hip and knee maximum flexion and extension angles and angular velocities did not show a significant difference between the normal and BFR conditions ($p > 0.428$), and there were trivial or small ES (0.003–0.362) and significant correlations ($r > 0.684$) between variables in normal and BFR conditions (Table 3).

Table 1. Spatiotemporal variables and corresponding difference, *p* value of a *t*-test, effect size (Cohen's d), and correlation coefficients between normal and blood flow restriction (BFR) conditions.

Variables (Units)	Normal	BFR	Difference	*p* Values	Effect Size	Correlation Coefficients (*p* Value)
Running speed (m/s)	6.61 ± 0.31	6.63 ± 0.35	0.02 ± 0.13	0.870	0.074	0.923 (<0.001)
Step length (m)	2.07 ± 0.15	2.07 ± 0.16	−0.01 ± 0.02	0.925	0.043	0.991 (<0.001)
Step frequency (Hz)	3.19 ± 0.16	3.22 ± 0.14	0.02 ± 0.05	0.762	0.138	0.953 (<0.001)
Support time (s)	0.143 ± 0.010	0.144 ± 0.010	0.001 ± 0.003	0.811	0.108	0.956 (<0.001)
Flight time (s)	0.171 ± 0.016	0.168 ± 0.016	−0.003 ± 0.003	0.653	0.204	0.983 (<0.001)

Table 2. Hip and knee joint angles and angular velocities at the foot strike (FS) and toe-off (TO) and corresponding difference, *p*-value of a *t*-test, effect size (Cohen's d), and correlation coefficients between normal and BFR conditions.

	Variables (Units)	Normal	BFR	Difference	*p* Values	Effect Size	Correlation Coefficients (*p* Value)
Right	Hip angle at FS (deg)	146.0 ± 4.5	145.8 ± 4.8	−0.1 ± 1.5	0.948	0.030	0.952 (<0.001)
	Hip angle at TO (deg)	201.4 ± 3.2	200.6 ± 4.1	−0.8 ± 1.7	0.642	0.211	0.929 (<0.001)
	Knee angle at FS (deg)	157.2 ± 3.2	157.0 ± 3.4	−0.2 ± 1.1	0.918	0.047	0.948 (<0.001)
	Knee angle at TO (deg)	161.4 ± 4.1	160.0 ± 4.0	−1.4 ± 1.5	0.455	0.342	0.928 (<0.001)
	Hip angular velocity at FS (deg/s)	125 ± 45	111 ± 35	−14 ± 21	0.445	0.349	0.889 (0.001)
	Hip angular velocity at TO (deg/s)	245 ± 44	268 ± 58	22 ± 30	0.352	0.427	0.867 (0.001)
	Knee angular velocity at FS (deg/s)	−387 ± 60	−412 ± 54	−25 ± 31	0.343	0.435	0.854 (0.002)
	Knee angular velocity at TO (deg/s)	−78 ± 79	−35 ± 80	43 ± 41	0.244	0.538	0.866 (0.001)
Left	Hip angle at FS (deg)	144.2 ± 4.4	144.0 ± 4.8	−0.2 ± 1.0	0.911	0.050	0.981 (<0.001)
	Hip angle at TO (deg)	202.3 ± 3.3	201.8 ± 4.3	−0.5 ± 1.9	0.791	0.121	0.904 (<0.001)
	Knee angle at FS (deg)	156.2 ± 5.0	155.7 ± 5.0	−0.5 ± 0.8	0.832	0.096	0.988 (<0.001)
	Knee angle at TO (deg)	162.2 ± 2.7	161.4 ± 3.5	−0.8 ± 2.2	0.563	0.263	0.788 (0.007)
	Hip angular velocity at FS (deg/s)	141 ± 44	136 ± 50	−5 ± 24	0.816	0.105	0.872 (0.001)
	Hip angular velocity at TO (deg/s)	254 ± 61	270 ± 63	17 ± 28	0.551	0.271	0.900 (<0.001)
	Knee angular velocity at FS (deg/s)	−385 ± 66	−397 ± 70	−12 ± 36	0.705	0.172	0.866 (0.001)
	Knee angular velocity at TO (deg/s)	−99 ± 95	−70 ± 91	29 ± 38	0.491	0.314	0.917 (<0.001)

Table 3. Hip and knee maximum flexion and extension angles and angular velocities during a stride cycle and corresponding difference, *p*-value of a *t*-test, effect size (Cohen's d), and correlation coefficients between normal and BFR conditions.

	Variables (Units)	Normal	BFR	Difference	*p* Values	Effect Size	Correlation Coefficients (*p* Value)
Right	Hip Max. Flexion angle (deg)	117.6 ± 3.1	118.7 ± 4.0	1.1 ± 1.6	0.496	0.311	0.931 (<0.001)
	Hip Max. Extension angle (deg)	204.2 ± 2.5	204.1 ± 3.9	−0.1 ± 1.9	0.964	0.020	0.910 (<0.001)
	Knee Max. Flexion angle (deg)	37.5 ± 4.9	38.6 ± 4.7	1.1 ± 1.6	0.608	0.234	0.946 (<0.001)
	Knee Max. Extension angle (deg)	169.4 ± 4.9	169.4 ± 5.6	>−0.1 ± 1.6	0.994	0.003	0.963 (<0.001)
	Hip Max. Flexion angular velocity (deg/s)	−656 ± 35	−660 ± 37	−4 ± 20	0.819	0.104	0.854 (0.002)
	Hip Max. Extension angular velocity (deg/s)	660 ± 39	647 ± 36	−14 ± 30	0.428	0.362	0.684 (0.029)
	Knee Max. Flexion angular velocity (deg/s)	−737 ± 82	−748 ± 79	−11 ± 25	0.765	0.135	0.952 (<0.001)
	Knee Max. Extension angular velocity (deg/s)	921 ± 64	936 ± 68	15 ± 32	0.623	0.224	0.888 (0.001)
Left	Hip Max. Flexion angle (deg)	118.9 ± 5.9	119.5 ± 7.0	0.6 ± 1.7	0.850	0.086	0.980 (<0.001)
	Hip Max. Extension angle (deg)	205.6 ± 3.1	205.9 ± 4.5	0.2 ± 1.9	0.892	0.062	0.931 (<0.001)
	Knee Max. Flexion angle (deg)	37.5 ± 4.5	38.8 ± 4.1	1.3 ± 1.4	0.517	0.296	0.955 (<0.001)
	Knee Max. Extension angle (deg)	170.5 ± 6.1	170.1 ± 6.8	−0.4 ± 1.1	0.880	0.068	0.991 (<0.001)
	Hip Max. Flexion angular velocity (deg/s)	−674 ± 48	−675 ± 59	>−1 ± 20	0.990	0.006	0.955 (<0.001)
	Hip Max. Extension angular velocity (deg/s)	692 ± 46	684 ± 46	−8 ± 32	0.711	0.168	0.758 (0.011)
	Knee Max. Flexion angular velocity (deg/s)	−757 ± 70	−767 ± 62	−11 ± 30	0.722	0.162	0.906 (<0.001)
	Knee Max. Extension angular velocity(deg/s)	922 ± 43	917 ± 39	−6 ± 26	0.758	0.140	0.804 (0.005)

4. Discussion

The current study aimed at comparing the lower limb kinematics between submaximal sprinting with and without BFR cuffs on the upper thigh. This study is the first to demonstrate no statistically significant effect of BFR cuffs on the kinematics of submaximal sprinting. In general, our hypothesis was supported by the results.

The results of this study show that the BFR cuffs on the upper thigh generally seem to have no large effect on the running kinematics at a running speed of 75–85% of the average speed of their best record of the 100-m race. To the best of our knowledge, there is no previous study which can be compared with the current results of the small or negligible influence of BFR cuffs on running kinematics. However, when compared to the difference in lower limb kinematics between running on a treadmill and over-ground [19,20], the influence of BFR cuffs using a moderate cuff pressure on running kinematics was substantially smaller than that of the difference in running conditions (e.g., difference in knee joint angle at FS was over 10 deg in the previous studies vs. less than 0.5 deg in this study). Moreover, the influence of BFR cuffs on the upper thigh on any joint angles (<1.4 deg) was smaller than the influence (≈5 deg) of inelastic taping on the ankle joint during running [13]. These results indicate that BFR cuffs on the upper thigh have no influence on over-ground running compared to running on a treadmill (which is broadly used as a training instrument), and running with inelastic taping. A recent study has revealed that the BFR during submaximal sprinting could result in an improvement of sprinting performance [11]. Therefore, BFR would be an effective training modality for improving sprinting performance through the development of muscular capacity with a small or negligible effect of cuffs on running kinematics.

There are some possible reasons for the lack of influence of BFR cuffs on over-ground running kinematics. The participants in this study performed running at the speeds of 75–85% of the participants' best records of 100-m race which were comfortable to them. At these running speeds, the range of hip angle and hip angular velocity in the sagittal plane would be relatively smaller than those at maximal running speeds [25,26]. This indicates that the running speeds in this study could allow participants to maintain their normal running kinematics when BFR cuffs were applied on their thigh. Another possible reason that could explain the small restriction of hip motion during running could be the moderate BFR cuff pressure (approximately 60% of estimated arterial occlusion pressure) used in this study.

There are some limitations in this study. We only performed the comparisons at a running speed of 75–85% of the participant's best record of the 100-m race, with a moderate cuff pressure, and with sprinters. Thus, it is possible that a larger influence of cuffs on running kinematics could be found at different running speeds, different cuff pressures, or with other cohorts. Moreover, because the BFR would increase fatigue, the results were possibly affected by the influence of fatigue.

5. Conclusions

This study confirmed that there is no influence of cuffs on the upper thigh on running kinematics. The findings in this study may promote the utilization of blood flow restriction on the upper thigh during sub-maximal running in a rehabilitation or training program.

Supplementary Materials: The following are available online at Supplementary materials can be found at www.mdpi.com/1422-0067/18/12/45/s1.

Author Contributions: Ryu Nagahara and Takashi Abe conceived and designed the experiments; Ryu Nagahara and Takashi Abe performed the experiments; Ryu Nagahara analyzed the data; Ryu Nagahara and Takashi Abe wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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