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The Effect of Whole-Body Compression Garments on Aerobic and Anaerobic Performance, 3-km Running Record and Physical Fitness in Amateur Marathoners

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Abstract

The purpose of this study was to determine the effect of whole-body compression garments on aerobic and anaerobic performance, 3-km running record and physical fitness in amateur marathoners. Ten male amateur marathoners without any medical problems were measured compression garments following non-compression garments intervention (n=10, age: 25.40±2.72 yrs.; height: 173.71±3.52 cm; weight: 70.55±7.16 kg; body mass index: 23.34±1.70). The compression and non-compression garments intervention were conducted at weekly intervals. We measured aerobic and anaerobic performance, 3-km running record, and the physical fitness according to each intervention. As a result, VO_{2max}, total exercise duration, anaerobic threshold were significantly higher in compression intervention than non-compression intervention. Also, minimum power was significantly higher in compression intervention than non-compression intervention. 3-km running performance was significantly faster in compression intervention than non-compression intervention. In addition, side-step was significantly faster in compression intervention than non-compression intervention. In conclusion, present study finding suggest that whole-body compression garments is beneficial to enhance aerobic performance and physical fitness.

Key words: compression garment, aerobic performance, anaerobic performance, 3-km running record, physical fitness

Introduction

Recreational running has become one of the most common physical activities worldwide, and the number of running events has increased, as has the number of competitions hosted by different cities in the world (Hulteen et al., 2017; Kozlovskaia et al., 2019; Dallinga, Van Rijn, Stubbe, & Deutekom, 2019). Participation is not just for friendly competition but for the improvement.

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Furthermore, majority of runners are paying almost as equal attention and effort as professional runners to improve their performance and runners are recognizing the importance of garment selection.

Recently, sporting apparel's material became lighter and functions diversified, and garments are evolving to maximize runner's performance at a time of sports activity. In sports and leisure activities, the function of garment is to maintain comfort of human body including moisture absorption and quick-drying, sun protection and antibacterial performance, etc. and to enhance physiological factors such as energy consumption and exercise efficiency to minimize the loads of body caused by walking and running (Bringard, Perrey, & Belluye, 2006; Kandhavadivu & Gopalakrishnan, 2021; di Prampero & Osgnach, 2019). In case of garments with flexible fabric, relatively less ease amount allows wearer to secure efficiency in body movement (Zakaria & Gupta, 2014). Some studies reported that compression stocking increased velocity of blood flow in deep-vein whereas it decreased venous stasis while enhancing venous blood return and release of CO_2 from the buffering of lactate (Pérez-Soriano, García-Roig, Sanchis-Sanchis, & Aparicio, 2019; Lovell, Mason, Delphinus, & McLellan, 2011). In addition, other studies reported that compression stocking improve peripheral circulation or venous blood return (Agu, Baker, & Seifalian, 2004) and compression tights reduced muscle oscillation during running exercise (Bringard, Perrey, & Belluye, 2006; Doan et al., 2003) and had positive effect on releasing lactic acid and muscle soreness (Mizuno, Morii, Tsuchiya, & Goto, 2016; Williams, McKendry, Morgan, & Breen, 2020; Rimaud el al., 2007). As such, compression garment is effective tool to reduce air resistance, enhance blood circulation of muscle, reduce muscle soreness and contribute to enhancing exercise performance.

With regards to compression garment and exercise performance, Kemmler and colleagues reported that lower body compression garment enhanced running performance and another study reported that functional wear for calf increased anaerobic power and delayed muscle soreness (Kemmler et al., 2009), thus, effective in fatigue recovery (Shin & Choi, 2016; Hill, Howatson, Van Someren, Walshe, & Pedlar, 2014). Scanlan and colleagues reported that compression garments increased professional cyclist's anaerobic power, while, had no significant difference in aerobic capability (Scanlan, Dascombe, Reaburn, & Osborne, 2008). Also, another study, lower body compression garments had positive effect on 40km cycling and recovery of 40-km cycling (de Glanville & Hamlin, 2012). Driller & Halson (2013) reported that the "whole body" compression garments enhanced the performance and facilitated oxygen exchange of exercising muscle during bicycling. As mentioned above, the preceding studies are limited to verifying the effect of lower body compression garments. In long-distance running, peripheral circulation and oxygen exchange as well as minimization of muscle oscillation of upper body and function of moisture, absorption and quick-drying are important. As such, it is necessary to verify the effect of whole body compression garments, which minimizes muscle oscillation of upper body and provides the function of moisture, absorption and quick–drying, in order to maximize the effect of compression garmenst. In addition, comprehensive competence needs to be confirmed by analyzing aerobic and anaerobic performance, 3-km running record, physical fitness factors according to wearing or not wearing whole body compression garments during sports activities such as running. Thus, the purpose of this study is to provide basic information for the necessity of functional wear at an endurance time by analyzing the effect of aerobic and anaerobic performance, 3-km running record and physical fitness factor.

Methods

Participants

This study targeted healthy 10 male runners in running club, who are in their 20s (n=10, age: 25.40±2.72 yrs.; height: 173.71±3.52 cm; weight: 70.55±7.16 kg; body mass index: 23.34±1.70). The subject of this study meets

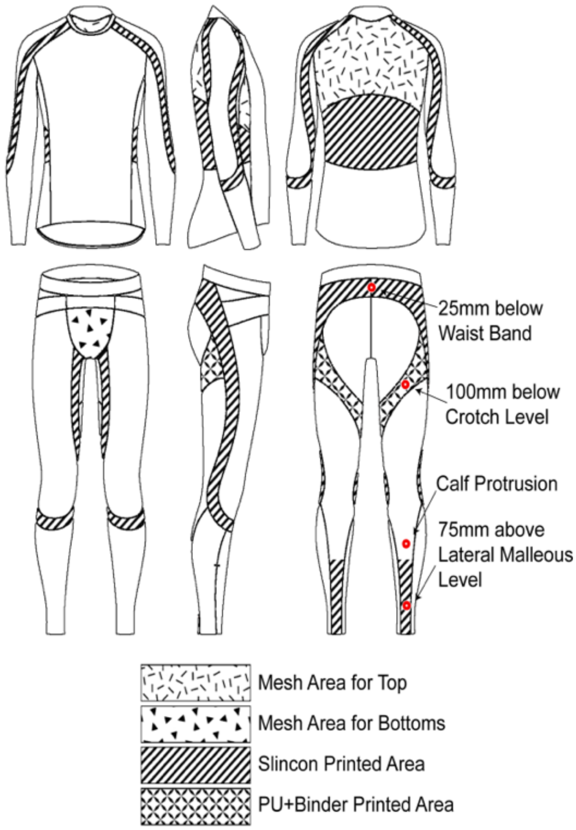

Figure 1. *Compression garments design, material arrangement and clothes pressure measuremen*

following criteria; 1) The male runner was a young adult in his twenties; 2) Normal weight adult with the height of 170~180cm; 3) Adult who regularly running exercises at least 3 times a week for the past three months; 4) Adult who does not take medicine or suffered from illness such as orthopedic disorder. Following completion of a health screening questionnaire, written informed consent was obtained from all participants after explaining the study purpose and procedure.

Methodology

Participants of the study visited laboratory and learned overall experimental process to be familiarized in measurement method before the experiment. All participants dealt with compression garments and control intervention. In accordance with each measure,

Table 1. *Standard for measurement of clothing pressure of compression garments Human body dimensions*

	Measuring Points				
	Stature	Circumference			
		Waist (Omphalion)	Hip	Thigh	Calf
Size (mm)	1750	800	940	560	374

Table 2. *Fabric properties of compression garments*

	Top		Bottoms	
	Main	Mesh	Main	Mesh
Knittng Method	Weft Knitting	Weft Knitting	Warp Knitting	Warp Knitting
Weight (g/m^2)	151	129	215	188
Composition (%)	PET 92 PU 8	PET 92 PU 8	Nylon 56 PU 44	PET 87 PU 13

aerobic performance, anaerobic performance, 3-km running record and physical fitness factor were measured. Each measure was conducted on weekly basis considering decline of performance record, resulted by fatigue. The participants were trained to minimize participation in exercise and abstain from drinking for a week. In addition, all the experimental procedures were conducted about 2-3 hours after breakfast.

Compression garments were silicone printed on anterior deltoid, biceps brachii, triceps brachii, posterior deltoid muscle to maximize the SSC effect of the muscles during running (Figure 1). Also, compression garments were silicone printed on gluteus maximus, vastus lateralis, vastus medialis, vastus medialis muscle, the extensibility and resilience of fabric were increased. Silicone printing increased the stability of joints during exercise by wrapping around the elbow and knee joints. Polyurethane and binder were printed to increase pressure on the hamstring area which is involved in the motion of the hip joint and the knee joint. Table 1 shows the clothing pressure measured in the state of wearing compression wear. Table 2 shows the fabric properties

Table 3. Result of Clothing pressure measurement

	Measuring Points			
	25mm below Waist Band	100mm below Crotch Level	Calf Protrusi-on	75mm above Lateral Malleous Level
Pressure (gf/cm^2)	43.5	37.0	63.0	92.5

of the compression wear. Table 3 shows the reference body dimensions used for the clothing pressure measurement. The clothing pressure presented in this study was measured with synthetic wear on synthetic mannequins with corresponding body dimensions. The clothing used as a control measure was short-sleeved T-shirt made of 100% cotton, short-sleeved blend of PET 90% and Poly Urethane 10%. The top is 90mm in the circumference of the chest, and the bottom has the margin of 160mm in the circumference of the buttocks so that the human body is not pressed.

In order to measure aerobic performance, this study used respiratory gas analyzer based on breath-by-breath. Laboratory maintained the temperature of 23~24℃ and treadmill with Bruce protocol was used to assess maximal exercise performance. The participants exercised until they reach exhaustion and when the subjects asked for suspension after sensing fatigue or disorder, the exercise came to a halt. At a time of exercise, participants were orally encouraged to reach maximal performance (Bruce, Kusumi, & Hosmer, 1973; Mieszkowski et al., 2020). Based on above measurements, VO_{2max} ($ml/kg/min^{-1}$), total exercise duration (sec), maximal heart rate (beats/min) were calculated.

In order to measure anaerobic performance, wingate test was conducted using cycle ergometer (Power Max V2, Combi, Japan). Five-minute light cycling was conducted before the measurement. Wingate test consists of five-second full force pedaling for ten times and 25-second break time between repetitions (Suzuki, Sato, Morimatsu, & Takamatsu, 2004). Peak power (W), minimum power (W), mean power (W), relative peak power (W/BW), relative minimum power (W/BW), relative mean power (W/BW) were calculated and fatigue index was calculated by using the formula of peak power and minimum power. The formula is as follows.

Fatigue index (%) = [(Peak power – Minimum power) / Peak power] x 100)

In order to measure 3-km running record, experiment was conducted in 400-m track. Before 3km running, low level running and stretching was conducted for 10 minutes. Stop watch was turned on with the starting signal and the participants ran to complete the full course at their fastest pace. When subjects completed 3-km running, record of stop watch was reflected as result value. Physical fitness factor was measured based on grip strength, back strength, sit-up, side step, sit and reach, trunk extension backward, one leg standing, squat jump and countermovement jump.

Statistics

The SPSS 21.0 (ver. Korea) was used for all data processing, and mean (M) and standard deviation (SD) were calculated by every measurement item. The validity of Kolmogorov-Smirnov and Shapiro-Wilk was verified, Paired t-test was conducted to define the difference in aerobic and anaerobic performance, 3km running performance and physical fitness factor between wearing and not wearing compression garments. Level of significance was statistically set at α=.05 for all data.

Results

Aerobic performance

Difference in aerobic performance according to wearing or not wearing compression garment intervention is suggested in Table 4. As a result, significant difference was shown in VO_{2max} with compression garment at 47.46±5.91 $ml/kg/min^{-1}$ and without compression garment at 44.11±4.68 $ml/kg/min^{-1}$

(p<.05). Significant difference was also shown in total exercise duration with compression garment at 770.80±60.01 sec and without compression garment at 733.70±53.32 sec (p<.05). The mean heart rate and maximal heart rate, there was no meaningful difference. Significant difference was shown in anaerobic threshold with compression garment at 22.07±4.16 ml/kg/min^{-1} and without compression garment at 17.00±4.24 ml/kg/min^{-1} (p<.05). As above result shows, this study confirms usefulness in enhancing aerobic performance by examining increase of VO_{2max}, total exercise duration and anaerobic threshold.

Anaerobic performance

Difference in anaerobic performance according to wearing or not wearing compression garments intervention is suggested in Table 5. The result shows that it was significantly higher with compression garment than without compression garment at the minimum power whereas no significant difference at peak power (p<.05). The compression garment at relative minimum power tended to be significantly higher than without compression garment (p=.051), whereas no significant difference between relative peak power and relative mean power. In addition, no significant difference was found in fatigue index between wearing and not wearing compression garments. Based on this result, this study confirms that wearing compression garments is useful in enhancing anaerobic performance by providing advantage at minimum power.

Table 4. *Difference of aerobic performance according to wearing compression garments*

Variables	CG(n=10)	CON(n=10)	*t*	*df*	*p*
VO2max (ml/kg/min^{-1})	47.46±5.91*	44.11±4.68	-2.383	9	.041*
Exercise duration time (sec)	770.80±60.01*	733.70±53.32	-3.701	9	.005*
HRrest (beats/min)	78.90±11.06	81.80±13.04	.505	9	.626
HRmax (beats/min)	194.50±7.32	192.40±6.64	-1.112	9	.295
Ventilation threshold (VT) (ml/kg/min^{-1})	22.07±4.16*	17.00±4.24	-3.948	9	.003*

Values are mean ± *SD*.
CG: compression garments intervention, CON: control intervention
*: p<.05, Difference from CON

Table 5. *Difference of anaerobic performance according to wearing compression garments*

Variables	CG(n=10)	CON(n=10)	*t*	*df*	*p*
Peak power (W)	665.10±87.37	652.70±107.68	.913	9	.385
Minimum power (W)	445.20±122.51*	398.60±112.23	2.290	9	.048*
Mean power (W)	542.66±118.17	521.46±116.63	1.865	9	.095
Relative peak power (W/BW)	9.47±.68	9.26±.78	1.078	9	.309
Relative minimum power (W/BW)	6.32±1.48	5.66±1.34	2.250	9	.051
Relative mean power (W/BW)	7.71±1.33	7.39±1.25	1.750	9	.114
Fatigue index (%)	33.49±13.94	39.09±12.61	-1.541	9	.158

Values are mean ± *SD*.
CG: compression garments intervention, CON: control intervention
*: p<.05, Difference from CON

3-km running record

Difference in 3-km running between wearing and not wearing compression garment intervention is suggested in Figure 2. The result shows significant difference between wearing compression garment with 897.30±156.90 sec and not wearing compression garment with 917.90±152.94 sec, hence, based on this result, this study confirms that wearing compression garments contributed to enhancing performance in 3-km running record (p<.05).

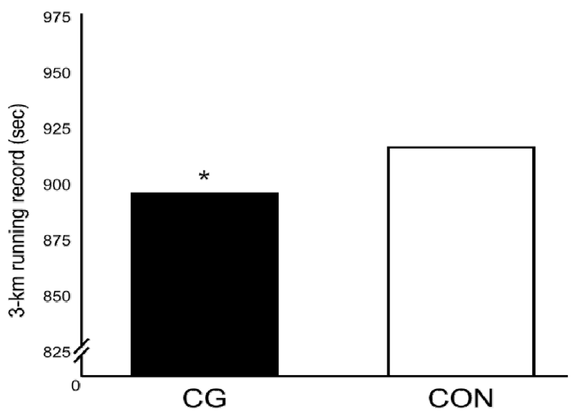

Figure 2. *Difference of 3-km running record according to wearing compression garments*
CG: compression garments intervention, CON: control intervention
**: p<.05, Difference from CON*

Physical fitness

Difference in physical fitness factor between wearing and not wearing compression garment intervention is suggested in Table 6. The result shows no significant difference between wearing and not wearing compression garment in both the left and right grip strength. In back strength, significant difference was found between wearing compression garment at 131.25±17.56 kg and not wearing compression garment at 122.05±19.14 kg. Sit-up, sitting trunk flexion, squat jump had no significant difference between wearing and not wearing compression garment. In side step, significant difference was shown between wearing compression garment at 26.70±24.80 count and not wearing compression garment at 24.80±2.30 count (p<.05). Also, trunk back extension tended to have significant difference between wearing compression garment at 50.50±9.25 cm and not wearing compression garment at 42.98±11.13 cm, and countermovement jump also showed tendency of significant difference in wearing compression garments at 36.21±5.83 cm against not wearing compression garments at 33.90±6.30 cm (p=.093).

Table 6. *Difference of physical fitness according to wearing compression garments*

Variables	CG(n=10)	CON(n=10)	t	df	p
Grip strength R. (kg)	43.23±3.58	43.72±4.31	-.367	9	.722
Grip strength L. (kg)	41.18±4.37	42.07±6.58	-.846	9	.419
Back strength (kg)	131.25±17.56*	122.05±19.14	2.597	9	.029*
Sit-up (count)	45.10±7.78	45.50±10.21	-.271	9	.793
Side step (count)	26.70±24.80*	24.80±2.30	2.890	9	.018
Sit and reach (cm)	8.75±7.56	8.32±7.66	.876	9	.404
Trunk extension backward (cm)	50.50±9.25	42.98±11.13	2.014	9	.075
One leg standing (sec)	46.97±25.33	43.36±27.27	.565	9	.586
Squat jump (cm)	31.21±5.82	29.40±5.67	.950	9	.367
Countermovement jump (cm)	36.21±5.83	33.90±6.30	7.882	9	.093

Values are mean ± *SD*.
CG: compression garments intervention, CON: control intervention
*: p<0.05, Difference from CON

Discussion

This study result shows that VO2max significantly increased with compression garments against not wearing compression garments intervention. This study confirms the advantage of compression garments in aerobic performance by significantly enhancing total exercise duration and anaerobic threshold. Compression garments reduces fatigue factor and facilitates recovery by stimulating blood circulation and oxygen delivery of muscle, thus, it is widely used in various sports activities (Troynikov et al., 2010; Troynikov, Nawaz, & Yermakova, 2013). Previous study reported that compression garments enhanced VO_{2max} and anaerobic threshold (Azhan, Hasan, Misnon, Raja Azidin, & Ismail, 2020; Ballmann, Hotchkiss, Marshall, & Rogers, 2019), and another study reported that compression garments increased total exercise duration and anaerobic threshold, however, reported result was similar to this study as no significant difference was observed in VO_{2max} (Kemmler et al., 2009). The VO_{2max} refers to capability of supplying oxygen to exercising muscle and it is used as an index of whole-body endurance (Iaia & Bangsbo, 2010; Wagner, 2010). The study result shows significant enhancement in VO_{2max} by virtue of wearing compression garments. Johnson and colleague reported that compression garments facilitate circulation by responding to increased internal pressure in vein and strengthening function of valve after massaging muscle (Johnson, Kupper, Farrar, & Swallow, 1982), increase of peripheral venous blood by pressurizing body increases stroke volume and cardiac output (Gandhi, Palmar, Lewis, & Schraibman, 1984; Lawrence & Kakkar, 1980). Compression garments increases blood flow, and the increased blood flow may to remove of lactate the exercising muscle allowing rapid redistribution to metabolic sites such as muscles, liver and heart (Belcastro & Bonen, 1975). It increases CO2 delivery to the lungs (Del Coso, Hamouti, Aguado-Jimenez, & Mora-Rodriguez, 2010). Due to this factor, it is believed that compression garments enhance body efficiency. In addition, this study observes significantly faster performance in 3-km running record when wearing compression garments against control intervention. The whole-body compression garments reduce unnecessary muscle tremor when body is in motion (Miyamoto, Hirata, Mitsukawa, Yanai, & Kawakami, 2011) and it is considered that compression garments has positive effect on 3-km running record by enhancing exercise efficiency. Furthermore, performance of 3-km running record may be interpreted in relation with result of aerobic performance of this study. This study observes significant increase of VO_{2max}, which refers to capability of supplying oxygen to muscle according to wearing or not wearing whole-body compression garments. However, this study has limitations on the effect of whole-body compression garments on hematological changes. If further research confirms hematological changes in clothing wear, it will support clearer results.

Meanwhile, this study verifies the effect of wearing compression garments on anaerobic performance and the result shows significantly high figure at minimum power and tendency of significantly high figures at peak power against control intervention (p=.095). The functional wear including compression garments not only fixates exercising muscle, surrounding muscle and joint but also plays an effective role in temperature adjustment and cramp prevention (Miyamoto, Hirata, Mitsukawa, Yanai, & Kawakami, 2011). Preceding study reported that compression garments reduce muscle fatigue and enhances athletic performance by having similar characteristic of taping therapy (Tariq, Haren, Kim, & Morley, 2005). Also, transveral loads or pressures can lead to more positive muscle contractile properties (Siebert, Till, Stutzig, Günther, & Blickhan, 2014). Hsu and colleague sugested that compression pressure of the lower extremities may effectively increase the effectiveness of muscle contraction (Hsu et al., 2017). In this study, compression garments intervention did not show significant enhancement at peak and mean power, still, it is considered meaningful to have the result of high performance at minimum power even with high result in wearing compression garments. This was possible because compression garments fixated muscle and joint, allowed exerting efficient power and delayed muscle fatigue by reducing muscle oscillation and maintaining joint stability.

According to the verification result of changing physical fitness factor with or without compression garments intervention, compression garments contributed to performance enhancement in back strength and side step, in other words, enhancement in agility. Moreover, this study confirms the possibility of contributing into dorsal flexibility and agility by having significantly high performance in trunk back extension and countermovement jump. This is considered as the contribution of elastic effect of compression garments into exerting muscle performance (Hooper et al., 2015; MacRae, Cotter, & Laing, 2011). Elastic material in compression garments contributes into pre-stretch function related to stretch shorting cycle (SSC) and has positive effect on exerting power in perspective of eccentric and concentric phase of each joint. In this connection, Komi reported that SSC increased muscle exertion in contraction velocity by quickly switching eccentric and concentric phase (Komi, 2000). In conclusion, whole-body compression garment is advantageous in enhancing aerobic performance, and somewhat positive effect is expected in anaerobic performance as well. Furthermore, this study confirms the possibility of contributing into muscle's agility. Nevertheless, this study has limitation of having small populations. This study has limitation of not defining specific mechanism with regards to the effects of aerobic and anaerobic performance according to wearing or not wearing compression garments. In addition, there are limitations that have been tested only on men for clear statistical verification. Above all, there is a limitation that fails to standardize the pressure of muscle between the participants. Therefore, this study expects further investigation on compression garment's effect in future studies by verifying aerobic and anaerobic performance, muscle activity and changing body temperature among more participants, including women.

Conclusions

This study finding suggest that whole-body compression garments is beneficial to enhance aerobic performance and physical fitness. Whole-body compression garments will be able to maximize exercise performance for long time the effect of long-term exercise such as half-marathon. This information will provide the amateur marathoners or running coach with basic data on performing an effective long-term exercise in the field of sports. The results of this study have limitations that cannot support the results based on hematological or hormonal changes. In future studies, hematologic variables such as lactic acid, ph and crp will be investigated to clarify the effect of whole-body compression garments.

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