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ORIGINAL ARTICLE

Effects of Wearing Functional Garment on Balance, Cervical Lordosis Angle, and Aerobic Performance in Amateur Runners: A Prospective Randomized Controlled Trial

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ABSTRACT
Background. The growing popularity of marathon running has increased interest in enhancing performance and preventing injuries. Balance, posture, and respiratory function are crucial for marathon runners. **Objectives.** This study investigated the effects of posture-correcting functional garments on male amateur runners' balance, cervical lordosis angle, and aerobic capacity. **Methods.** Thirty male amateur marathon runners (aged 30–50 years) were randomly assigned to either an experimental group (EG, n=15), wearing functional garments designed for posture maintenance and spinal correction during both training and daily activities, or a control group (CG, n=15), without garments. The intervention lasted 4 weeks, with both groups participating in aerobic running sessions thrice weekly. Static balance, the primary outcome, was assessed using the Biodex Balance System to measure the overall stability index (OSI), anterior-posterior stability index (APSI), and medial-lateral stability index (MLSI). Cervical lordosis angle was assessed using craniovertebral angle (CVA) measurements, and aerobic capacity was evaluated using the Bruce protocol for maximum heart rate (HRmax), maximal oxygen consumption (VO_2max), and rating of perceived exertion (RPE). Statistical analysis was conducted using two-way repeated measures analysis of variance. **Results.** Participants in the EG showed significant improvements in static balance (OSI and APSI; P<0.001 and P=0.012, respectively), CVA (P=0.021), and VO_2max (P<0.001) than those in the CG. **Conclusion.** Functional garments enhance balance, posture, and aerobic capacity in male amateur runners, offering potential performance and injury prevention benefits. Further studies should investigate long-term effects and applications in diverse athletes.

INTRODUCTION

Marathon running is a prominent endurance sport that tests athletes' physical limits and has gained significant popularity among amateur participants. In the U.S., the number of marathon events increased from 300 in 2000 to over 1,200 in 2014, with finishers increasing from 353,000 to over 550,000 during the same period (1).

A critical aspect of marathon running is optimizing energy efficiency through properly managing stride length and speed, particularly during the stride phase (2). Efficient runners typically make initial ground contact with the ball or outer part of the foot, followed by the whole-foot contact. Proper foot landing, guided by the body's center of mass, is essential to prevent excessive force and requires a strong balance to enhance nerve activation and muscle control (3, 4).

The nervous system continuously receives inputs from the visual, vestibular, and proprioceptive systems to control muscles and regulate balance, which is crucial for maintaining stability during long-distance running, such as in marathons. Poor balance is the leading cause of sports-related injuries and can impair performance (5, 6).

Maintaining proper cervical lordosis is essential for maintaining postural stability and running efficiency. Abnormalities such as forward head posture (FHP) can negatively affect respiratory function, increase cervical spine stress, and lead to conditions such as neck pain, headaches, and other musculoskeletal disorders (7, 8).

FHP also weakens the respiratory muscles, significantly impairing respiratory function. Previous studies have shown that individuals with FHP exhibit lower forced vital capacity (FVC), forced expiratory volume in 1s (FEV1), and reduced accessory respiratory muscle activity compared to those with normal posture (9).

The importance of functional garments in long-distance running, such as marathons, has been increasingly recognized. These garments enhance performance by regulating body temperature, wicking sweat, and minimizing friction, thereby preventing skin irritation and injury. Features such as breathability, stretching, lightweight construction, and antimicrobial properties help runners stay comfortable and reduce the risk of chafing. Selecting appropriate functional garments can improve performance and aid injury prevention and recovery (10).

Previous studies have shown that functional garments applied to the lower extremities, using performance apparel, can improve running performance (11). In addition, functional garments have been shown to reduce fatigue, decrease lactic acid production, prevent muscle vibration and damage, reduce edema, improve circulation, and accelerate recovery following exercise (11). Previous studies confirmed that wearing compression garments on the lower extremities can improve athletic performance. Therefore, this study investigated the effect of wearing functional garments developed for posture maintenance and spinal correction through an ergonomic design by analyzing the upper body's balance ability, cervical lordosis angle, and aerobic capacity.

MATERIALS AND METHODS

Participation. The inclusion criteria for this study were males in their 30s and 50s registered with a marathon federation who actively competed in marathons and consistently participated in aerobic running training at least thrice weekly. The exclusion criteria included individuals with orthopedic injuries to the upper or lower extremities that would prevent participation in running training, a history of acute coronary syndrome or cardiovascular disease, a body mass index (BMI) of 30 kg/m² or higher, or those who had received or were currently receiving treatment for neck-related issues.

The sample size was calculated using the G*power 3.1 program, with an effect size of 0.25, power of 0.95, and significance level of 0.05. Considering a potential dropout rate of 20%, 30 participants were recruited. The participants were randomly assigned to either the experimental group (EG, n=15), which participated in aerobic running training while wearing functional garments, or the control group (CG, n=15), which participated in aerobic running training without functional garments. Randomization was conducted by a therapist blinded to the study, using a randomization control program (https://www.randomizer.org/) during pre-interviews. All participants were informed about the study's purpose, methods, and potential risks and provided written informed consent.

Study Design. This study was a prospective, randomized, controlled, single-blind trial, and all procedures were approved by the Institutional Review Board of Korea National Sports University (approval number: 20240613-066). The study protocol was conducted in accordance with the ethical principles of the Declaration of Helsinki, as reflected in the a priori approval by the institution's human research committee. The study followed a two-point design consisting of a baseline, four-week, and post-intervention measurements. The detailed study procedure is shown in the CONSORT flowchart (Figure 1).

Primary Outcome. Static balance was assessed as the primary outcome using the Biodex balance system (BBS) (Shirley, NY, USA). The BBS is a mobile platform that ranges from levels

1 to 12, with level 1 being the least stable and level 12 the most stable. The platform allows a surface tilt up to 20° across a full 360-degree range. The degree of platform tilt, in conjunction with computer software version 1.32 (Biodex Medical Systems, Shirley, NY, USA), was used to generate an overall stability index (OSI), anterior-posterior stability index (APSI), and medial-lateral stability index (MLSI).

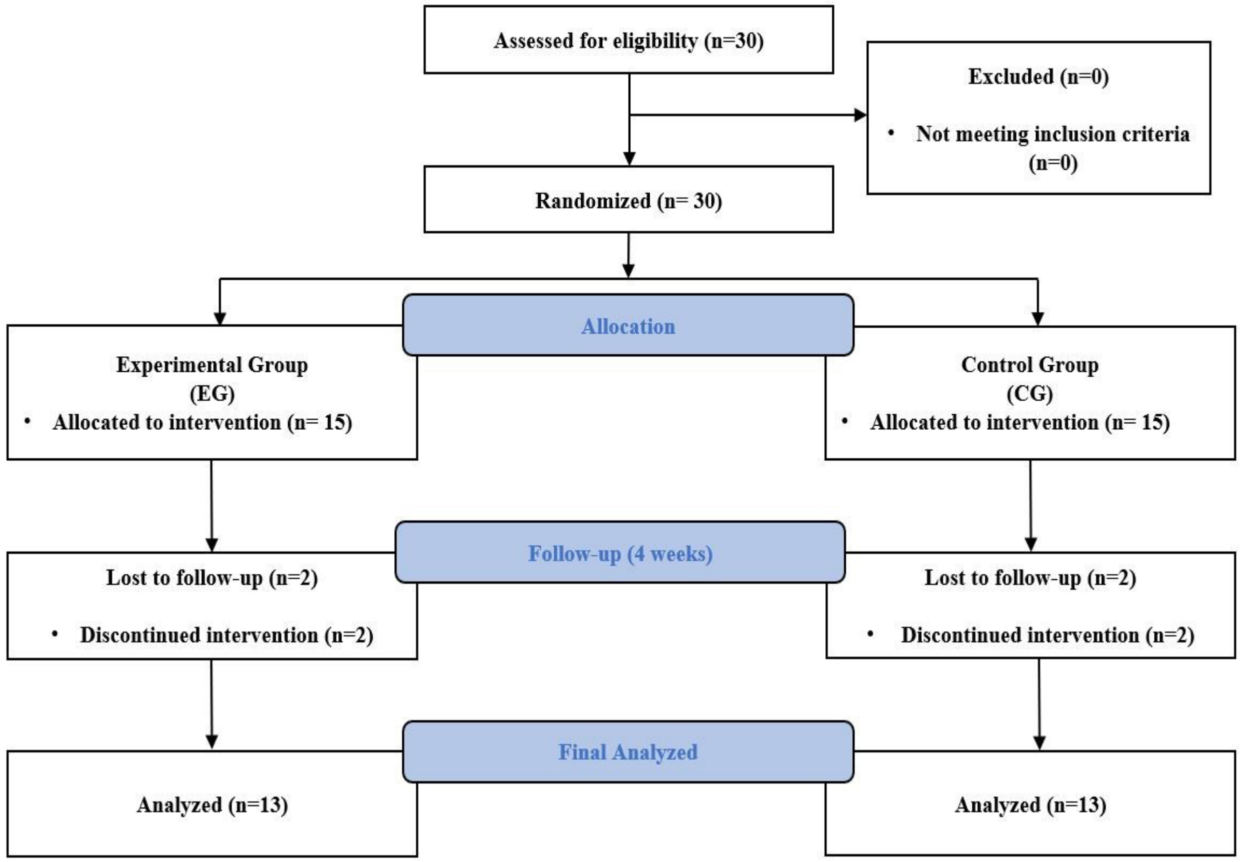

Figure 1. CONSORT flow diagram.

APSI and MLSI represent the platform displacement from the horizontal in the sagittal plane (Y) and coronal plane (X), respectively. OSI is defined as the sum of the APSI and MLSI. The formula for generating OSI is [(∑ (0 - Y)^2 + (0 - X)^2 / sample)] 0.5, APSI is [(∑ (0 - Y)^2 / sample)] 0.5, and MLSI is [∑ (0 - X)^2 / sample] 0.5. The test was conducted at level 1 with the participant standing on one leg (barefoot) on a platform and placing their hands next to their pelvis. During the test, the participants were instructed to keep the supporting leg slightly bent at the knee (15-30 degrees) and focus on the monitor, where visual feedback was displayed. The participants were instructed to keep the pointer representing the center of the platform aligned with the target shown on the monitor. The test was administered following three practice trials, with a 10-s break between each trial. During the test, a foul was considered if the participant used their hands to hold the handles to maintain balance or if their non-weight-bearing foot touched the ground. Measurements were taken three times each at levels 12, 6, and 1, and the average was used for the analysis (12).

Secondary Outcome.

Cervical Lordosis Angle. The secondary outcome of this study, cervical lordosis angle, was assessed by measuring the craniovertebral angle (CVA) using photographic techniques, a standard method for assessing forward head posture. The CVA was the angle between a line drawn from the 7th cervical vertebra to the tragus (earlobe) and a vertical line passing through the 7th cervical vertebra. Markers were placed at each anatomical site prior to measurement.

During the measurements, the participants stood comfortably with their arms at their sides. The self-balancing posture method, which involved three repetitions of cervical flexion and extension, was used to ensure that the head was in a neutral position. This technique prevents voluntary adjustment of the head position. The participants were instructed to look straight ahead to avoid visual influences on their posture.

Three measurements were taken, and the values used for analysis were considered reliable based on a Cronbach's alpha value of 0.80 or higher. The measurements were recorded with an accuracy of 0.01 degrees. CVA is considered one of the most objective methods for assessing forward head posture, with a test-retest reliability of r=0.88.

Aerobic Performance. Aerobic capacity, another secondary outcome, was assessed using graded exercise testing. The test was performed using the Bruce protocol on a graded exercise treadmill (Medtrack ST 55, Quinton Instrument Co., USA) and analyzed using a Quinton Metabolic Cart (QMC; Quinton Instrument Co., USA) and an automated pulse monitor (Model 412, USA). Measurements were recorded in mixed chamber mode at 15-s intervals. The key parameters for the analysis included the maximum heart rate (HRmax), maximal oxygen consumption (VO_2max), and rating of perceived exertion (RPE). The exercise test was a progressive, symptom-limited exercise test, with termination criteria based on the American College of Sports Medicine (ACSM) guidelines. Upon completion of the exercise test, recovery was monitored by having participants walk at a slow speed of 2.7 km/h for 3 minutes during the recovery period.

Intervention.

Aerobic Running Training. The intervention for this study involved aerobic running training in both groups. Participants were trained three times per week for a total of 4 weeks. Each session included a 10-minute warm-up, 40 minutes of aerobic running, and a 10-minute cool-down. The exercise intensity was controlled to remain below 80% of the individual's target heart rate (THR), which was calculated using the Karvonen formula (13).

Compliance with the exercise program was monitored via telephone. After each session, participants were required to report to the researchers, providing details on whether they had completed the exercise, including the intensity and duration of the session. These self-reports were used to assess the participant's compliance with the exercise program and ensure the intervention's consistency.

Functional Garment. Participants in the experimental group (EG) were instructed to wear a functional garment (Mr. Poly, Dodream Creative, Seoul, Korea) during aerobic running training and in their daily lives. Made from a blend of polyester and spandex, Mr. Poly features a high stretch and ergonomic design to support the body's natural movements. It provides optimal support and stability during various activities and helps minimize fatigue (Figure 2). In this study, participants in the EG were provided six pairs of functional garments and monitored for compliance with daily wear time.

Statistics. Data analysis was performed using SPSS software for Windows (version 23.0, Chicago, Illinois, USA). The Results are expressed as means, standard deviations, and standard errors of 95% confidence intervals (CI). Normality of distribution was tested using the Shapiro-Wilk test, continuous data were analyzed using the independent t-test, and nominal data were tested for homogeneity using Fisher's exact test. Differences in all dependent variables across periods were assessed using two-way repeated-measures analysis of variance. Post hoc tests for period differences were performed using the Bonferroni correction for simple main-effect comparisons. Group differences in outcome measures were expressed as effect sizes (ES), calculated using Cohen's d, and categorized as small (<0.2), medium (0.5), or large (>0.8). The statistical significance was set at p=0.05.

RESULTS

Thirty participants were enrolled in this study; however, two individuals dropped out of both groups, leaving 13 participants in each group for the final analysis. One of the participants withdrew due to an ankle injury, while the other three dropped out for personal reasons. The remaining participants had a mean age of 52.12 ± 4.33 years, 171.35 ± 5.78 cm in height, 68.31 ± 5.41 kg in weight, and exhibited a body mass index of 23.3 ± 1.57. Detailed demographic information for the study participants is presented in Table 1.

Table 1. Baseline characteristics (N=26)[a].

	EG (n=13)	CG (n=13)	Δ (95% CI)	*P* value
Age (years)	51.77 ± 4.99	52.46 ± 3.73	0.69 (-4.26–2.87)	0.692[b]
Height (cm)	170.08 ± 4.66	172.62 ± 6.67	2.54 (-7.19–2.12)	0.272[b]
Weight (kg)	66.32 ± 3.88	70.3 ± 6.11	3.98 (-8.13–0.16)	0.059[b]
BMI (kg/m^2)	22.99 ± 1.36	23.6 ± 1.76	0.61 (-1.88–0.67)	0.335[b]
BFM (kg)	15.98 ± 3.87	19.12 ± 4.39	3.15 (-6.5–0.2)	0.064[b]
SSM (kg)	31.5 ± 2.39	33.2 ± 2.62	1.7 (-3.73–0.33)	0.097[b]

EG: Experimental group; CG: Control group; CI: Confidence interval; BMI: Body mass index; BFM: body fat mass; SSM: skeletal muscle mass; [a]: Data are expressed as mean (standard deviation); [b]: Independent t-test.

Primary Outcomes. For the primary outcome of static balance, the OSI did not differ significantly between the groups (P=0.236). However, significant differences were observed within groups (P<0.001), and an interaction effect of time x group (P<0.001, Δ [95% CI]: 3.06 [-4.76–-1.37], ES=1.5). Post hoc analysis revealed that participants in the EG showed significant improvement following the intervention (P<0.001, Δ [95% CI]: 4.25 [2.97-5.54]), whereas those in the CG did not exhibit significant changes (P=0.472, Δ [95% CI]: 0.45 [-0.83–1.74]). The APSI did not show a significant difference between the groups (P=0.734). However, there was a significant difference within EG (P=0.001) and an interaction effect of time × group (P=0.012, Δ [95% CI]: 1.15 [-2.96–0.67], ES=0.5). In the post hoc analysis, the EG showed improvement after the intervention (P<0.001, Δ [95% CI]: 2.04 [1.14–2.94]), while the CG did not change (P = 0.472, Δ[95% CI]: 0.36 [-0.54–1.26]). The MLSI did not show significant differences between or within the groups (P=0.862, P=0.235, respectively), and there was also no interaction effect of time × group (P=0.235, Δ[95% CI]: 0.58 [-2.07–0.90]). The primary outcomes are shown in Figure 3.

Secondary Outcome. The details of the secondary outcomes are shown in Table 2. Significant differences existed in the CVA between and within the groups (P=0.021 and P=0.001, respectively). However, no interaction effect of time × group (P=0.142) existed. In the post hoc analysis, participants in the EG showed improvement after the intervention (P=0.001), while CG participants did not change (P=0.105). HRmax did not show a significant difference between or within groups, nor was there an interaction effect of time × group (P=0.226, P=1.000, P=0.226, respectively). Conversely, VO_2max showed significant differences between and within the groups and an interaction effect of time × group (P=0.010, P=0.003, P<0.001, respectively). The RPE did not show any significant difference between or within groups, nor was there an interaction effect of time × group (P=0.663, P=0.121, P=0.381, respectively).

Figure 2. Functional garment design and application. (A) Front view of the functional garment designed for posture maintenance and spinal correction. (B) The back view shows adjustable elastic components for spinal support. (C) The participant was wearing the garment during testing.

Table 2. Pre and Post-Differences in Dependent Variables[a].

Outcome	EG (n=13)			CG (n=13)			Mean difference (95% CI)[c]	d
	Pre	Post	Mean Change[b]	Pre	Post	Mean Change[b]		
CVA	1.46 ± 1.56	3.38 ± 1.56	1.92* (-2.96–-0.89)	0.23 ± 2.86	1.08 ± 1.89	0.85 (-1.88–0.19)	2.31† (0.91–3.71)	1.3
HRmax	171.31 ± 8.35	172.15 ± 7.54	0.85 (-2.83–1.14)	172.23 ± 3.39	171.38 ± 2.72	0.85 (-1.14~2.83)	0.77 (-3.82–5.36)	0.1
VO_2max	47.48 ± 5.84	52.83 ± 4.40	5.35* (-7.45–-3.25)	45.08 ± 5.63	44.43 ± 4.87	0.65 (-1.45–2.75)	0.31§† (-1.06–0.45)	1.8
RPE	18.54 ± 0.88	19.08 ± 0.76	0.54 (-1.17–0.09)	18.85 ± 0.99	19.00 ± 0.82	0.15 (-0.78–0.47)	0.08 (-0.56–0.72)	0.1

EG: Experimental Group; CG: Control Group; CI: Confidence Interval; d: Cohen's d effect size; CVA: Craniovertebral angle; HRmax: Maximum heart rate; VO_2max: Maximal oxygen consumption; RPE: Perceived exertion; [a]: Data are expressed as mean (standard deviation); [b]: Post-hoc analysis with Bonferroni correction; *: Significant difference within the group; [c]: Two-way repeated analysis of variance; †: P<0.05 (Between groups), §: P<0.05 (Interaction effect).

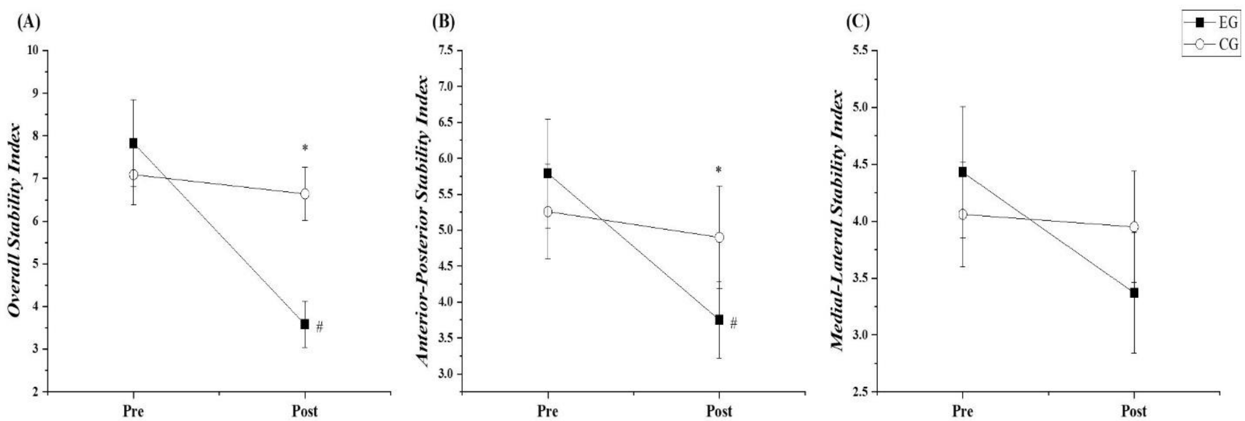

Figure 3. Outcome of the Biodex balance system for Static balance. (A) Overall stability index. (B) Anterior-Posterior stability index. (C) Medial Lateral stability index.

DISCUSSION

This study examined the effects of functional garments on balance, posture, and aerobic capacity of male amateur runners. The results showed that wearing a functional garment significantly improved static balance and postural alignment, particularly regarding CVA. In addition, participants in the EG exhibited an increase in aerobic capacity. However, no significant differences were observed in the HRmax and RPE between the groups.

Balance is crucial in long-distance running, such as marathons, because it helps maintain the body's center of mass, reduces muscle and joint stress, and prevents injury. It also optimizes muscle function and energy efficiency (14). In this study, balance ability, measured by the OSI and APSI, improved significantly in the experimental group (EG) compared to the control group (CG) after the intervention. This improvement was linked to an enhancement in cervical vertebral alignment (CVA), with the EG showing better CVA than the CG.

These findings are consistent with those of Park et al. (15), who reported that cervical alignment improvements enhanced static and dynamic balance after chiropractic and shoulder flexibility exercises. Similarly, other studies have highlighted the significant roles of neck and spinal stability in postural control and balance

(16). Studies have also shown neck and spine stability significantly influences postural control and balance. Cervical alignment plays a key role in maintaining gaze, as patients with malalignment often develop compensatory mechanisms, such as increased upper cervical lordosis. As the cervical deformity worsens, compensatory changes in cervical and pelvic alignment may further affect the overall balance (17).

Another reason for improved balance is that functional garments assist in balance control through the pressure exerted on the skin. The effect of compression garments, similar to that of functional garments, on balance is mediated by mechanical stimuli applied to the skin, which are transmitted to the nervous system, enhancing the sensory input. This stimulus primarily affects the mechanoreceptors in the ankles and legs, allowing the nervous system to regulate posture and balance more effectively. According to previous research, compression garments provide additional sensory signals to the central nervous system by stimulating the skin, which helps to reduce body sway when visual input is limited or when the posture is unstable (18).

Furthermore, compression garments can inhibit spinal reflexes, reduce excessive muscle reactions, and control the small movements necessary for maintaining balance. By lowering reflex intensity, compression garments help reduce unnecessary movements that can disrupt balance (19). Moreover, compression garments complement the neural mechanisms required for balance control by integrating sensory information and offering extra somatosensory input to compensate for the lack of visual cues, thereby improving balance (20). Therefore, the functional garments worn in this study may have effectively enhanced balance.

In this study, the improvement in CVA could be attributed to the stabilizing effects of the functional garments on the upper body. According to Gascon et al. (21), enhanced scapular positioning achieved through compression helps reduce neck and shoulder compensatory movements. This mechanism could explain the improved CVA in the EG, as the compression garment likely helped maintain the natural curvature of the cervical spine by minimizing unnecessary movements and promoting optimal muscle alignment around the neck and upper back (21).

Although there were no between-group differences in HRmax and RPE in this study, there were improvements in VO_2max in the EG. These improvements may be indirectly related to the improved running economy provided by compression garments. While research indicates that compression garments have minimal direct effects on cardiovascular responses, such as maximal heart rate or plasma lactate concentration, they positively impact running efficiency. For instance, one study reported that compression garments reduced oxygen consumption during running by approximately 9% at speeds between 10 and 16 km/h (22). This improvement in running economy suggests that, even without direct cardiovascular benefits, compression garments allow runners to use oxygen more efficiently at submaximal intensities, potentially contributing to increased endurance and improved VO_2max over time.

However, this study had certain limitations. First, the participants were male amateur marathon runners, which limits the generalizability of the findings to other sexes or athletic levels. Second, the short duration of intervention limited the assessment of long-term effects, necessitating further study. Third, exercise intensity was self-reported by both groups, which introduced potential variability due to uncontrolled external factors. Future research should explore the long-term effects of functional garments and include diverse populations, such as female athletes or participants from different sports, to broaden the applicability of these findings.

CONCLUSION

The findings of this study highlight the potential benefits of functional garments in enhancing balance, posture, and aerobic performance in amateur runners. These findings suggest that incorporating ergonomic functional garments into training regimens may improve stability, reduce fatigue, and aid injury prevention and recovery. Further research should consider exploring the long-term effects of functional garments on performance and injury prevention and their impact on different athletic populations. Investigating the different types of functional garments and their effects on biomechanics and comfort could provide further insights into their practical applications in sports.

APPLICABLE REMARKS

- This study suggests functional garments can improve male amateur runners' balance, cervical posture, and aerobic capacity.
- Athletes and coaches may benefit from incorporating these garments into training to enhance performance and reduce injury risks.
- The garments may help maintain stability and prevent posture-related injuries during long-distance running.

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AUTHORS' CONTRIBUTIONS

Study concept and design: Jae Keun Oh. Acquisition of data: Han Soo Park. Analysis and interpretation of data: Han Soo Park. Drafting the manuscript: Han Soo Park. Critical revision of the manuscript for important intellectual content: Mu Yeop Ji. Statistical analysis: Han Soo Park. Administrative, technical, and material support: Mu Yeop Ji. Study supervision: Jae Keun Oh.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

FINANCIAL DISCLOSURE

We have no financial interests related to the material in the manuscript.

FUNDING/SUPPORT

This study was conducted without any external financial or material support. All resources and equipment were provided by the researcher's institution or personally acquired by the researcher.

ETHICAL CONSIDERATION

This study was conducted in accordance with the principles outlined in the Declaration of Helsinki. Ethical approval was obtained from Korea National Sport University, with approval number 20240613-066. All participants provided written informed consent prior to participation.

ROLE OF THE SPONSOR

The funding organization had no role in the design and conduct of the study; collection, management, analysis of the data; or preparation, review, and approval of the manuscript.

ARTIFICIAL INTELLIGENCE (AI) USE

The authors did not use AI or AI-assisted technologies in the writing process of this manuscript.

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