Journal of Sports Sciences, 2003, **21**, 601–610

Taylor & Francis
health**sciences**

Evaluation of a lower-body compression garment

BRANDON K. DOAN,[1] YOUNG-HOO KWON,[2] ROBERT U. NEWTON,[3]* JAEKUN SHIM,[4] EVA M. POPPER,[4] RYAN A. ROGERS,[4] LORI R. BOLT,[4] MIKE ROBERTSON[4] and WILLIAM J. KRAEMER[5]

[1]Human Effectiveness Directorate, Brooks Air Force Base, TX 78235, USA, [2]The Biomechanics Laboratory, Texas Women's University, Denton, TX 76201, USA, [3]School of Biomedical and Sports Science, Edith Cowan University, Perth, WA 6027, Australia, [4]Biomechanics Laboratory, Ball State University, Muncie, IN 47306, USA and [5]The Human Performance Laboratory, The University of Connecticut, Storrs, CT 06269, USA

Accepted 20 March 2003

The aims of this study were to determine how custom-fit compression shorts affect athletic performance and to examine the mechanical properties of the shorts. Ten male and 10 female track athletes on a university's nationally competitive track team, specializing in sprint or jump events, participated in the study. Testing utilized the compression shorts with loose-fitting gym shorts as the control garment. Several significant effects were revealed for the custom-fit compressive garment. Although 60 m sprint time was not affected, hip flexion angle was reduced. Skin temperature increased more and at a faster rate during a warm-up protocol. Muscle oscillation was decreased during vertical jump landing. Countermovement vertical jump height increased when the participants were wearing the custom-fit compression garment. In materials testing, the elasticity of the compressive garment provides increased flexion and extension torque at the end range of extension and flexion, respectively, and may assist the hamstrings in controlling the leg at the end of the swing phase in sprinting. The compressive garment significantly reduced impact force by 27% compared with American football pants alone. Through various mechanisms, these findings may translate into an effect on athletic performance and a reduction in injuries.

Keywords: athletic performance, ergonomic aid, injury, jump, sprint.

Introduction

The use of compression garments in athletics and fitness activities is becoming more widespread. Style, reduced chaffing, injury prevention, anecdotal and research-supported evidence of performance enhancement are all reasons cited for wearing these compressive garments. An examination of recent elite track and field contests documents the popularity of compressive garments.

Early research on compressive garments focused on increased venous blood flow due to the compression and its positive effects on venous thrombosis in post-operative patients. Compressive stockings and tights caused a reduction of venous stasis in the lower extremities (Sigel *et al.*, 1975; O'Donnell *et al.*, 1979; Gandhi *et al.*, 1984; Perlau *et al.*, 1995). Berry and McMurray (1987) conducted the first exercise-related research on compressive garments, finding lower blood lactate concentrations after maximal exercise when the stockings were worn during the exercise. In a series of investigations of Lycra-type compression shorts, Kraemer *et al.* (1996, 1998) noted enhanced athletic performance. Specifically, compressive shorts have been shown to enhance repetitive jump power (Kraemer *et al.*, 1996, 1998). Possible mechanisms contributing to the increased repetitive vertical jump performance include a reduction in muscle oscillation, improved proprioception and increased resistance to fatigue.

The compression shorts (Antibody Inc., Cheltenham, MD) used in this study were very different to traditional spandex or Lycra® compression shorts and may represent the next advance in sports garments, working to maximize physical performance and the ergonomic interface with the athlete. The garment is custom-fit to be hyper-compressive (15% smaller than the athlete's measurements) and is made of 75% closed cell neoprene and 25% butyl rubber; the garment is 4.76 mm thick. This garment is much more compressive, elastic and impact-absorbing than previously

---

* Author to whom all correspondence should be addressed.
e-mail: r.newton@ecu.edu.au

Journal of Sports Sciences ISSN 0264-0414 print/ISSN 1466-447X online © 2003 Taylor & Francis Ltd
DOI: 10.1080/0264041031000101971

studied compressive garments and may elicit different benefits or detriments to athletic performance.

The aims of this investigation were to determine how these custom-fit compression shorts affect athletic performance and to examine the mechanical properties of the shorts. Specific performance and mechanical tests were designed to assess the effect of the garment on muscle oscillation, jump power, skin temperature, impact absorption and elasticity.

Methods

Participants

The participants were 10 male (height 1.79 ± 0.07 m, age 20.0 ± 0.9 years, body mass 74.1 ± 8.3 kg) and 10 female (height 1.69 ± 0.03 m, age 19.2 ± 1.3 years, body mass 60.2 ± 5.2 kg; mean $\pm s$) track athletes on a university's nationally competitive (National Collegiate Athletic Association, Division I) track team specializing in sprint or jump events. The study was approved by the Institutional Review Board committee of the university. The athletes were fully informed of the aims and risks of participation in this investigation and signed informed consent documents before testing.

Garment

The compression shorts (Model 950 GH, Antibody Inc., Cheltenham, MD) used in this study were very different from traditional spandex or Lycra compression shorts. The garments were custom-fit based on girth and inseam measurements of each participant's waist, hip, thigh and knee. The garment runs from just above the knee to just above the waist and is a 15–20% smaller representation of the participant's lower body, while the material will expand to almost 100% of the original measurements while compressing tissues underneath. The garment material is made to be light, strong, compressive and impact-absorbing and consists of 75% closed cell neoprene and 25% butyl rubber; the garment is 4.76 mm thick. Additionally, the garment has a sticky inner surface designed to maximize compression and elasticity by preventing it from sliding on the skin surface.

Experimental procedures

Testing utilized the compression shorts with loose-fitting gym shorts as the control garment. Both conditions for each of a series of performance tests (60 m sprint, jump power and muscle oscillation) were conducted on the same day using a balanced, randomized block design to remove day-to-day variation. Each participant was allowed several familiarization trials before each performance test. After completing one performance test, the participant rested for 10–20 min and then crossed over and completed the other test condition. For the skin-temperature test, however, each condition was tested on different days in the afternoon, still using a balanced, randomized block design. Test results were compared within participants for the compressive garment and control conditions. The participants performed a standardized warm-up protocol before each test session.

60 m sprint (range of motion) test

One 60 Hz video camera (Panasonic WV-D5100HS) interfaced with a video recorder was positioned at a right angle to the runner's path at the 55 m mark of a 60 m sprint to record kinematic data. Highly reflective markers were placed on the left temple–mandibular joint, left leg over the greater trochanter, lateral epicondyle of the femur and lateral malleolus.

Kwon 3D, version 2.1 (Kwon3D, Muncie, IN) motion analysis software was used to digitize and analyse the kinematic data. Before analyses, the data were filtered using a fourth-order low-pass Butterworth filter with a cut-off frequency of 6 Hz (Winter, 1990). Hip and knee joint range of motion, calculated as the difference between the maximum and minimum values for the hip and knee, were compared between conditions. Photocells were positioned at the start and finish of the race to measure 60 m times (see Fig. 1). Athletes rested for a minimum of 10 min between conditions.

Muscle oscillation

The participants were videotaped performing countermovement jumps to compare thigh muscle oscillation between the compressive garment and control conditions. The participants were instructed to dip down to a comfortable depth and jump for maximum height, while keeping their hands on their hips throughout the movement. One 60 Hz video camera was positioned to record the sagittal plane view of each jumper. Highly reflective markers were placed on the left leg over (1) the greater trochanter, (2) the lateral epicondyle of the femur and (3) the antero-lateral aspect of the thigh midway between the anterior-superior iliac spine and the superior aspect of the patella (Fig. 2).

Peak Performance, version 5.3.0 (Peak Performance Technologies Inc., Englewood, CO) motion analysis software was used to digitize and analyse the kinematic data. Before analyses, the data were filtered using a fourth-order low-pass Butterworth filter with a cut-off frequency of 12 Hz (Winter, 1990). Maximum longitudinal and anterior-posterior displacement of the thigh marker was calculated relative to the hip and knee markers and compared between conditions.

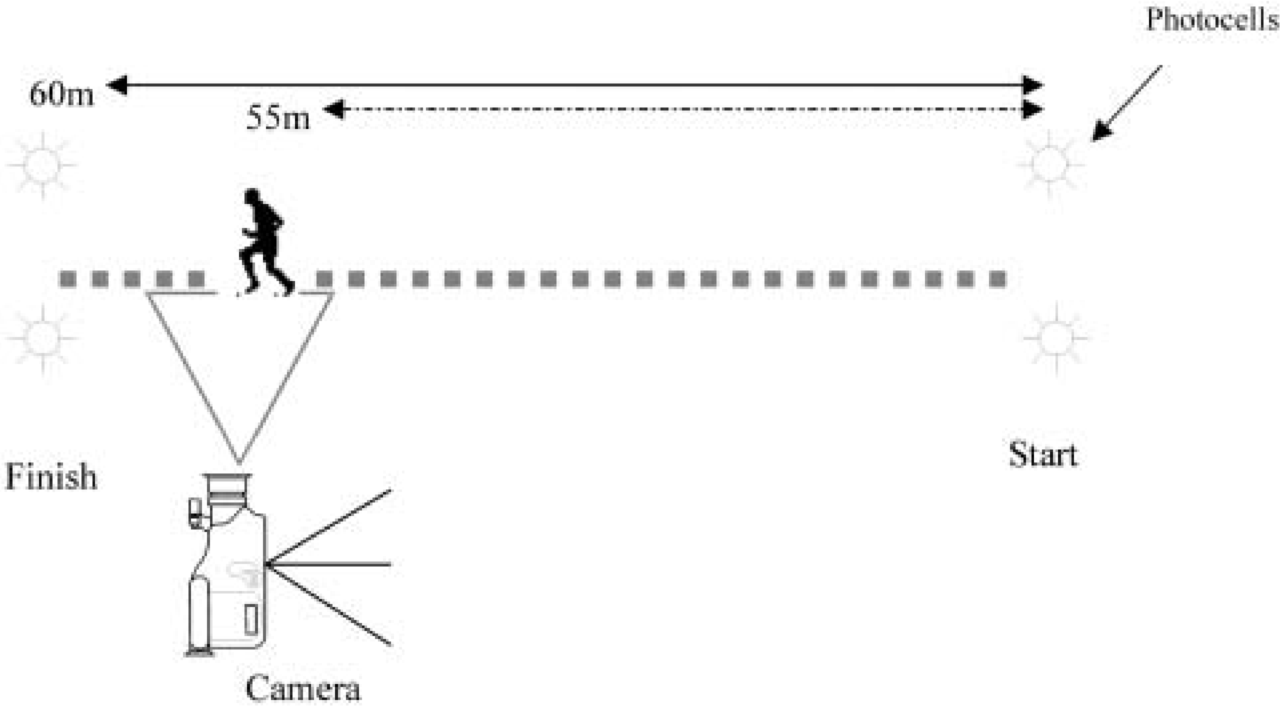

Fig. 1. Experimental set-up for the video camera and photocells for the 60 m sprint tests.

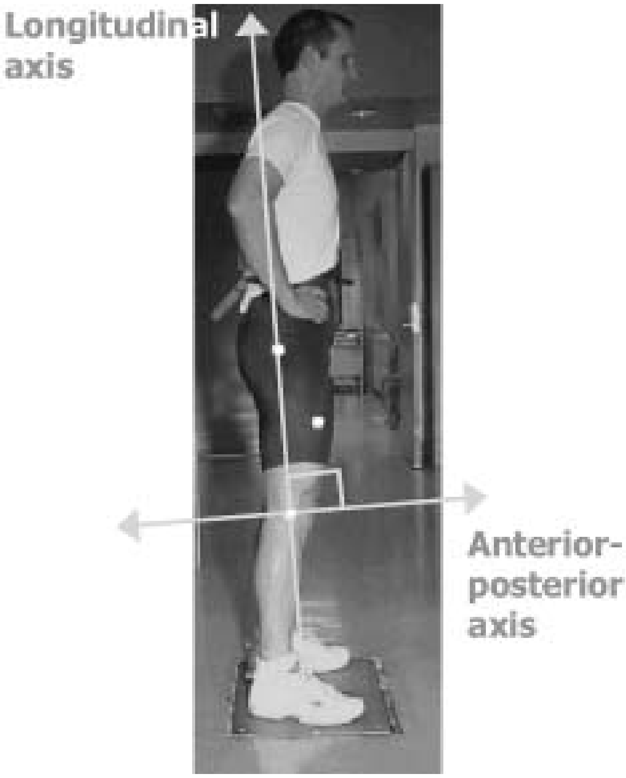

Fig. 2. Experimental set-up for measurement of muscle oscillation. Reflective markers are shown attached to the hip, knee and mid-thigh.

Jump-power test

Maximal-effort countermovement jumps were performed as a measure of jump power. The participants were instructed to dip down to a comfortable depth and jump for maximum height, while keeping their hands on their hips throughout the movement. The participants practised jumping until they were comfortable and consistent. Jump heights were measured with a Celesco cable transducer (Celesco, CA) attached to the participant's waist (Fig. 3). Vertical ground reaction force data were recorded at 500 Hz with a Kistler force plate (Kistler Instrument Corporation, Amherst, NY) and analysed with Ballistic Measurement System (Innervations, Muncie, IN) computer software. The participants performed three trials, unless the third jump was much higher than the first and second jumps, when four or more jumps were performed until jump height stopped increasing. Even though the participants performed a standard warm-up and were trained jumpers, some of them took more than three jumps to attain maximal height.

Skin temperature

The participants pedalled on a cycle ergometer for 5 min with 1.5 $W \cdot kg^{-1}$ of body weight resistance. Two type-T copper-constantin thermocouples were secured under the compressive garment and loose-fitting con-

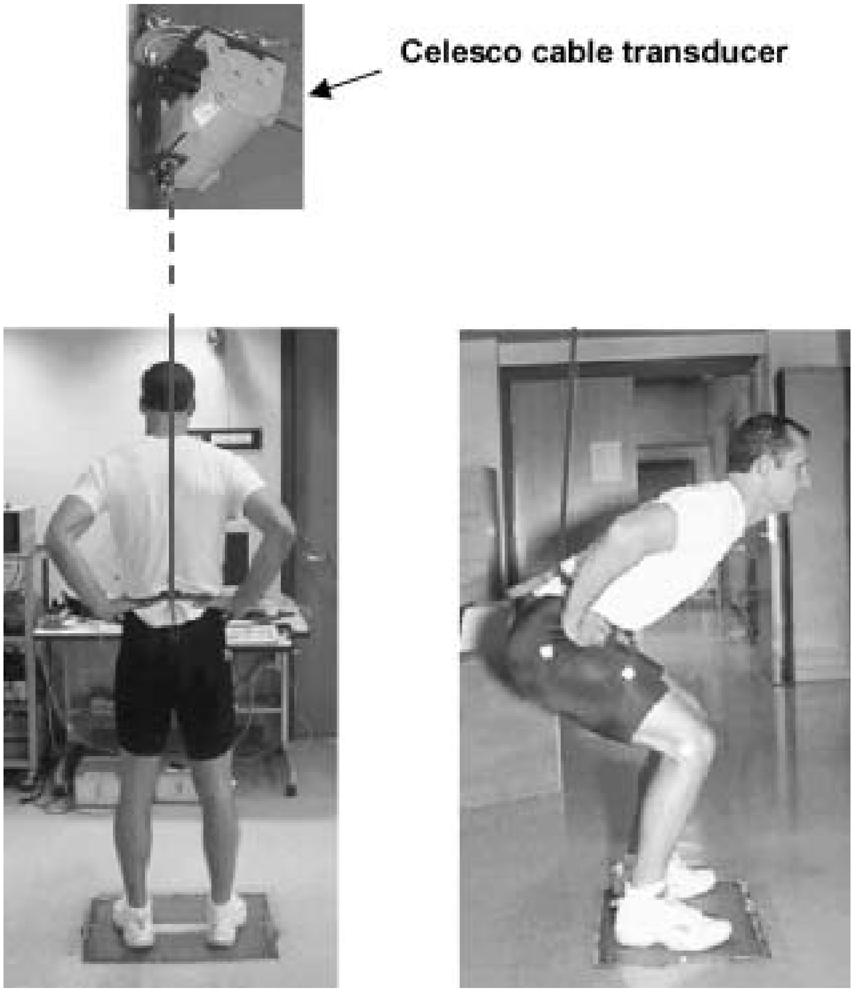

Fig. 3. Experimental set-up for the countermovement jump tests.

trol shorts with breathable tape (Kendall, Polyskin II, Mansfield, MA) 24 cm above the superior aspect of the patella. Temperature was recorded using an Iso-Thermex (Columbus Instruments, Columbus, OH) system linked to an Apple computer. Temperature was measure immediately before the warm-up protocol, once each minute during the warm-up and immediately after warm-up. The other treatment condition was tested on a different day to ensure return of skin temperature to normal between trials. Ambient temperature was measured and controlled between conditions.

Mechanical characteristics of garment

Impact

Standard impact testing was conducted on the garment material to assess the impact attenuation properties of the garment. An American collegiate American football helmet weighted to a total mass of 5.44 kg was repeatedly dropped on a force plate from 36.1 and 76.2 cm. The helmet was dropped onto a normal pair of American football pants for the control condition and onto a swatch of the compressive garment material for the experimental condition (see Fig. 4). Vertical ground reaction force was recorded at 7000 Hz with a Kistler force plate (model number 9281B) and the data analysed with Bioware (Kistler Instrument Corporation, Amherst, NY) computer software. Peak force values were compared between conditions.

Elasticity

The garment was fitted to a life-size mannequin cast from a human specimen with full joint range of motion (Gatesville Doll, MA56237) to measure the elastic properties of the garment. Force data were collected at 200 Hz on Biopac Acq*Knowledge* (version 3.5.2) computer software (Biopac Systems, Inc.) using an

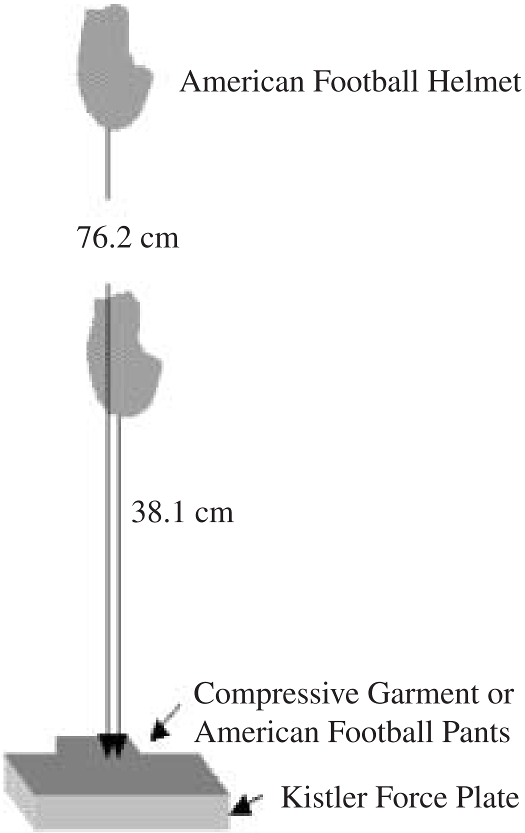

Fig. 4. Experimental set-up for the measurement of impact force.

Entran (Fairfield, NJ) force transducer (see Fig. 5). The mannequin was tested through a normal sprinter's hip range of motion, as determined in the sprint test of this study, with and without the garment. The force transducer was connected at a 90° angle to the distal end of the mannequin's thigh segment and to a stationary point at two hip flexion (127° and 158.5°) and two hip extension (195° and 200°) angles. Force was measured with and without the compressive garment on the mannequin and the amount of torque at the joint was calculated. The garment was made to fit the mannequin; however, the skin of the mannequin did not have the same elastic and frictional properties with the garment as human skin. The aim of this test was to produce a reasonable estimate of the human joint torques caused by the garment.

Data analysis

Means and standard deviations were computed for the conditions with and without the compressive garment. A two-tailed, paired *t*-test was used to establish whether the means were significantly different. The criterion for statistical significance was set at $P \leqslant 0.05$.

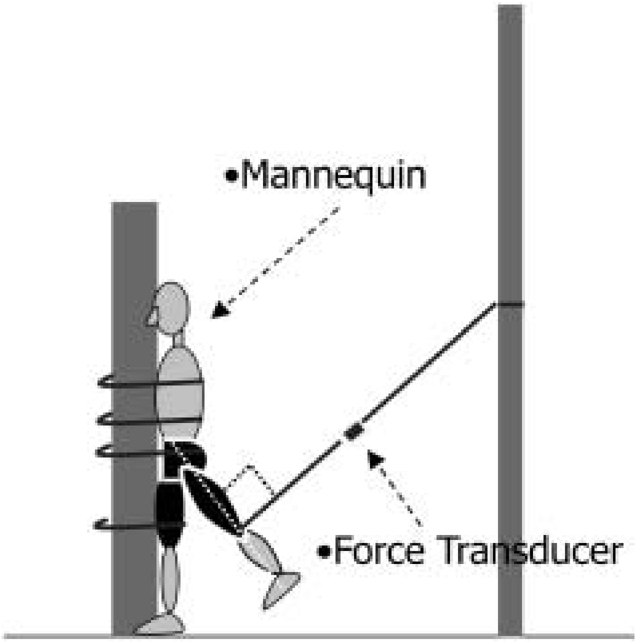

Fig. 5. Experimental set-up for determination of the effects of the compressive garment on hip joint torque.

Results

60 m sprint (range of motion) test

When the men and women were combined, there was a significant ($P = 0.04$) reduction in hip range of motion during a sprint in the compressive garment condition. For the men-only and women-only groups, hip range of motion did not change. Knee range of motion for all groups was not significantly different between conditions; however, there was a trend towards a decrease in range of motion (Fig. 6). There was no significant difference when comparing 60 m sprint times between experimental conditions (Fig. 7).

Muscle oscillation

There was a significant reduction in both longitudinal and anterior-posterior thigh musculature oscillation during vertical jump landing in the compressive garment condition for men and women ($P = 0.013$ for all groups) (Fig. 8).

Jump-power test

When men and women were combined, single maximal countermovement vertical jump height increased significantly ($P = 0.015$) from 0.461 to 0.485 m for the control and compressive garment conditions, respectively (Fig. 9). Also while wearing the compressive garment, squat depth in single maximal countermove-

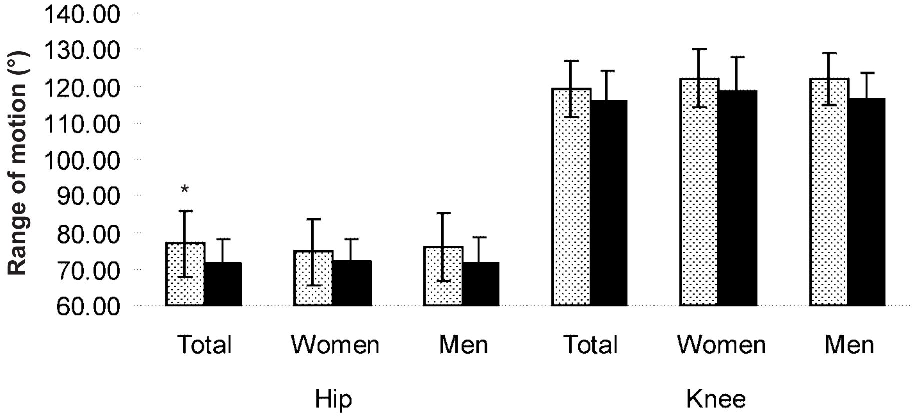

Fig. 6. Hip and knee range of motion (mean ± *s*).*Significant difference between the compressive garment (solid) and the control condition (stippled): $P \leqslant 0.05$.

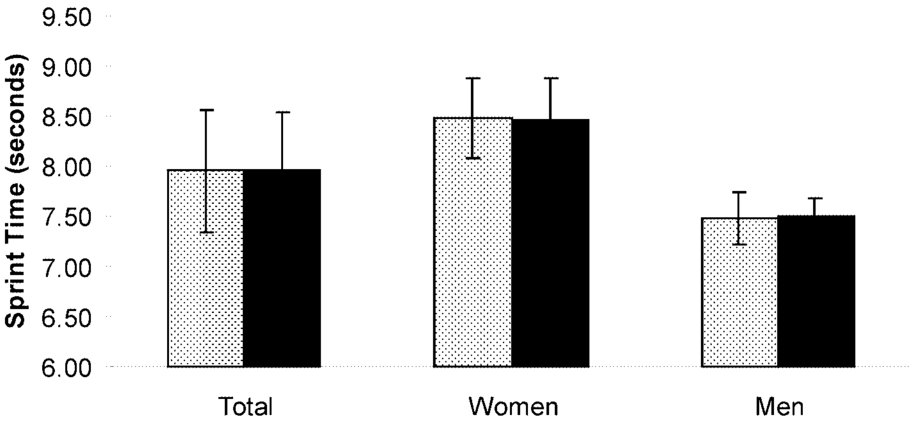

Fig. 7. Sixty-metre sprint times (mean ± *s*). Compressive garment (solid), control garment (stippled).

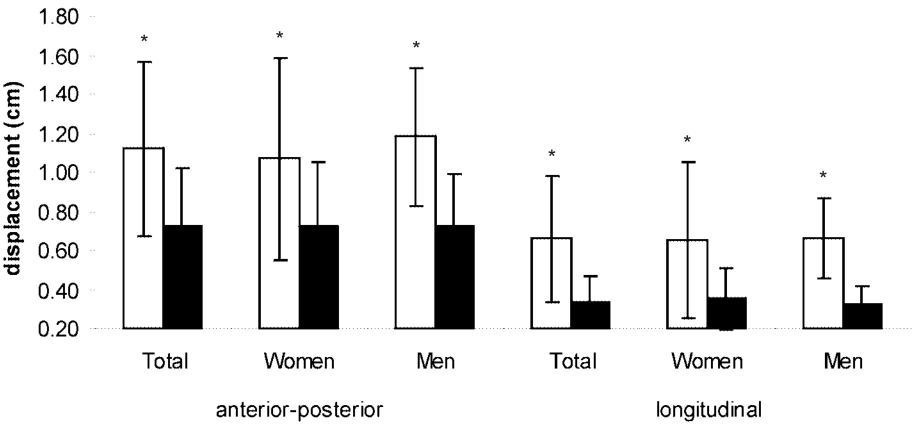

Fig. 8. Anterior-posterior muscle oscillation (mean ± *s*). *Significant difference between the compressive garment (solid) and the control condition (open): $P \leqslant 0.05$.

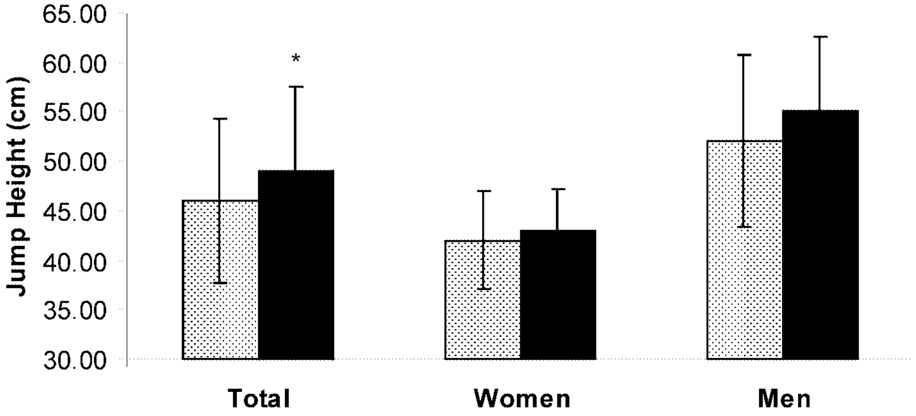

Fig. 9. Maximum countermovement jump height (mean ± *s*). *Significant difference between the compressive garment (solid) and the control condition (stippled): $P \leqslant 0.05$.

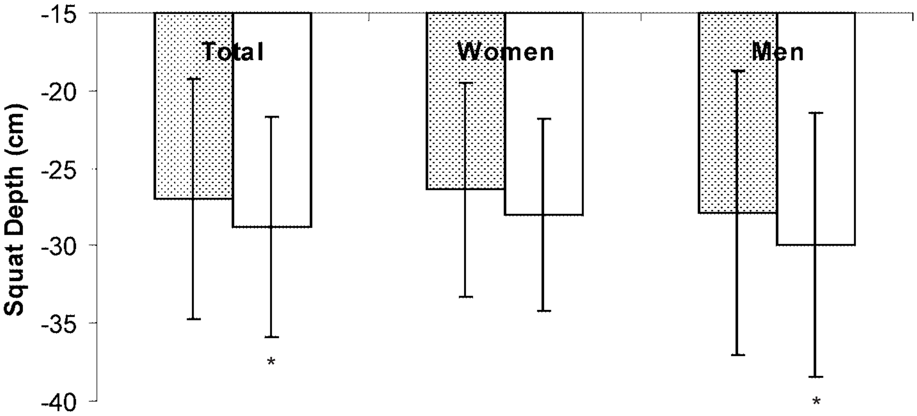

Fig. 10. Minimum countermovement jump squat depth (mean ± *s*). *Significant difference between the compressive garment (open) and the control condition (stippled): $P \leqslant 0.05$.

ment vertical jumps decreased significantly from 0.279 to 0.299 m for men ($P = 0.024$) and from 0.270 to 0.288 m for the combined group of men and women ($P = 0.016$) (Fig. 10).

Skin temperature

The garment also caused a significant increase ($P = 0.003$ for men and women) in skin temperature compared with the loose-fitting gym shorts during a 5 min warm-up (Fig. 11).

Mechanical characteristics of the garment

According to the impact testing performed in this study, 26.6% of the impact forces were significantly ($P = 0.000$) attenuated by the garment at a drop height of 38.1 cm, while 11.6% ($P = 0.066$) of the impact forces were attenuated at a drop height of 76.2 cm (Fig. 12). The elasticity of the garment increased torque at the hip joint by 53–91% during 127° and 158° flexion and by 191–285% during 200° and 195° extension, respectively (Fig. 13).

Discussion

In this study, we observed several possible effects the customized compression garment may have on athletic performance. Skin temperature increased during a warm-up protocol, muscle oscillation decreased significantly during vertical jump landings and countermovement vertical jump height increased when the garment was worn. The elasticity of the garment provides increased flexion and extension torque at the end range of extension and flexion, respectively. Lastly, hip joint range of motion decreased slightly during a 60 m sprint. Through various mechanisms, these

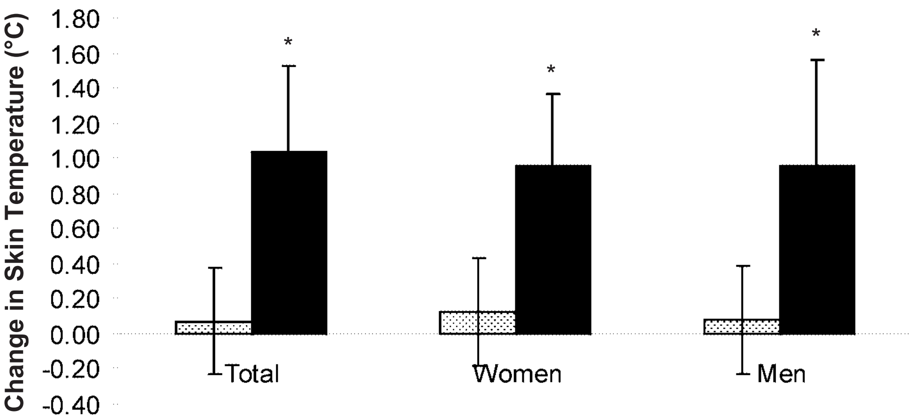

Fig. 11. Change in skin temperature (mean ± *s*). *Significant difference between the compressive garment (solid) and the control condition (stippled): $P \leqslant 0.05$.

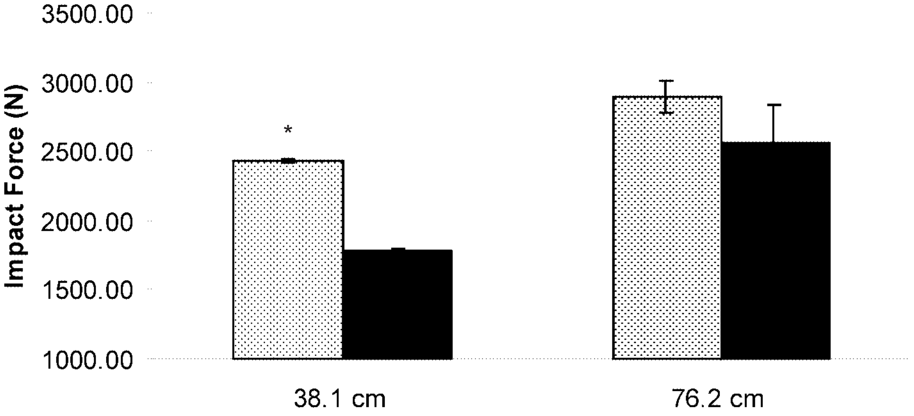

Fig. 12. Impact force measured from drop heights of 38.1 and 76.2 cm (mean ± *s*). *Significant difference between the compressive garment (solid) and the control condition (stippled): $P \leqslant 0.05$.

findings may translate into an effect on athletic performance and a reduction in injuries.

60 m sprint (range of motion) test

Based on the kinematic results of this study, the compressive garment resulted in a decrease in hip joint range of motion during sprinting, primarily due to a reduction in maximum hip flexion angle. The participants ran the same speed, however, with decreased hip range of motion (–5.08°), which may mean the garment increases stride frequency. However, this was not measured in the current study and is purely conjecture at this time. What is important to note is that there was no dramatic change in the kinematics of sprinting and so the garment does not appear to interfere with the motion of the hip or knee. The elasticity of the garment may increase the acceleration of the leg as it comes down. However, the garment may be a hindrance near full hip extension, as it produces a small opposing torque beyond 180° of hip extension. Additionally, the garment may reduce injury by assisting the eccentric action of the hamstrings at the end of the recovery phase (Kujala *et al.*, 1997).

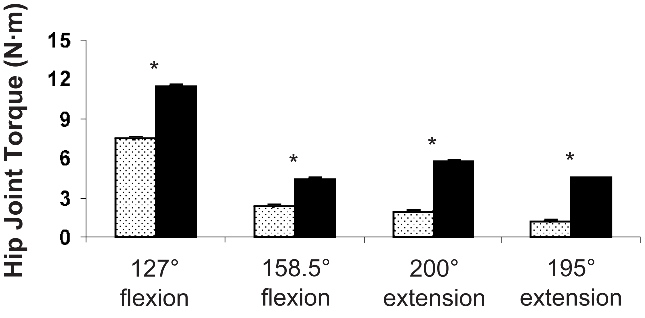

Fig. 13. Mannequin hip joint torque (means ± *s*). *Significant difference between the compressive garment (solid) and the control condition (stippled): $P \leqslant 0.05$.

Muscle oscillation

We found significantly reduced longitudinal (0.32 cm) and anterior-posterior (0.40 cm) muscle oscillation upon landing from a maximal vertical jump. Similar results have been reported for Lycra-type compression shorts and the reduction in oscillation has been speculated to contribute to increases in repetitive jump performance by enhancing technique and reducing fatigue (Kraemer *et al*., 1998). The proposed ergonomic mechanism is that a reduction in the oscillatory displacement of the muscle may optimize neurotransmission and mechanics at the molecular level (McComas, 1996).

Jump-power test

Previous studies have reported that single maximal vertical jump power output is not affected by compressive shorts composed of varying percentages of Lycra (Kraemer *et al*., 1996). The compressive shorts used in this study, however, which consist of neoprene and butyl rubber, are much thicker and may provide significant additional elastic force for single maximal jump performance. In fact, the countermovement vertical jump test results showed that the maximal jump height of the athletes in the compressive garment condition was significantly higher than that in the control condition by 2.4 cm. The elasticity of the garment may have increased the propulsive force, resulting in a higher jump. Also, because we noted a significantly lower squat depth with the garment, the mechanical support of the garment may have allowed a more optimal (lower by 1.8 cm) squat depth to be performed, resulting in a greater impulse in the concentric phase of the jump. Additionally, previous studies have shown improved proprioception with compressive garments (Barrack *et al*., 1983; Perlau *et al*., 1995; Kraemer *et al*., 1998), which may improve jump technique. A compression sleeve worn on the knee was shown to improve the integration of the balance control system and muscle coordination (Kuster *et al*., 1999). There are many possible mechanisms that may contribute to the increase in single maximal jump performance. Determination of the exact mechanisms will require further study.

Skin temperature

An initial increase in skin temperature may translate into increased athletic performance and a reduced potential for injury. Bergh and Ekblom (1979) found that performance in short-term, power-related athletic events, such as jumping and sprinting, was decreased below, and enhanced above, normal muscle temperature. Maximal dynamic strength increased and the force–velocity curve shifted, causing a higher velocity of shortening at a given load as a function of muscle temperature (Bergh and Ekblom, 1979; Sargeant, 1987). It has also been reported that skin temperature is related to blood flow and muscle temperature (Isaji *et al*., 1994). Muscle function has been shown to be optimal at 38.5°C (Åstrand and Rodahl, 1977). According to the results of the present study, the garment will decrease warm-up time to this optimal temperature, thereby enhancing muscle performance. Additionally, studies have shown that increased musculotendinous temperature may reduce the potential for injury (Agre, 1985; Kujala *et al*., 1997). It should be noted, however, that the garment may increase muscle temperature beyond optimal in activities at long duration or in hot environments, possibly causing a decrease in performance.

Mechanical characteristics of the garment

Mechanical testing revealed some further potential benefits the garment may have for athletic performance. The results of the elasticity test indicate a significant amount of torque is provided by the garment at the hip joint at the joint angles tested. The torque provided by the garment may assist the hamstrings in slowing the leg at the end of the hip flexion phase in running, which may reduce eccentric activation of the antagonists. The hamstrings are compromised at the end of the swing phase in sprinting as they are being simultaneously lengthened over the hip and knee joints. If the hamstrings cannot provide sufficient force to slow the limb and accelerate it to ground contact, muscle tears can result. The added hip flexion torque provided by the garment at the end of the swing phase may assist in reducing this common sport injury. The garment may also aid the athlete in the propulsive phases of sprinting and jumping. Impact testing revealed that the garment is effective at attenuating some impact forces. This may be valuable for impact-related injury prevention in contact sports and sports associated with a high incidence of falling.

Conclusions

Wearing custom-fit compressive shorts did not change sprinting speed over 60 m; however, it may have an effect over longer distances, such as 100–400 m, but this needs to be determined experimentally. It is clear that wearing the custom-fit compression garment improves warm-up in terms of skin temperature attained and increases vertical jump height. Muscle oscillation on landing from a jump is considerably reduced and this may have benefit in terms of reduced tissue injury and enhanced performance with repeat jumps. The tight fit and elastic nature of the Antibody garment results in a considerable torque being generated about the hip joint at the flexion and extension ranges of motion encountered during sprinting. This may have a performance enhancement and injury-reduction role by assisting the muscles in generating torque. In particular, this may assist the hamstrings in limiting hip flexion at the end of the swing phase, a time that is particularly risky for hamstring injuries. In addition, the material used in the custom-fit compression garment is capable of attenuating impact forces and this may have some benefit when worn during contact sports.

Disclaimer and acknowledgements

The views expressed in this article are those of the authors and do not reflect the official policy or position of the United States Air Force, the Department of Defense or the US Government. Financial support for this study was provided by Antibody Inc., Cheltenham, MD 20623, USA.

References

Agre, J.C. (1985). Hamstring injuries: proposed aetiological factors, prevention, and treatment. *Sports Medicine*, **2**, 21–33.

Åstrand, P.O. and Rodahl, K. (1977). *Textbook of Work Physiology*. New York: McGraw-Hill.

Barrack, R.L., Skinner, H.B., Cook, S.D. and Haddad, Jr. R.J. (1983). Effect of articular disease and total knee arthroplasty on knee joint-position sense. *Journal of Neurophysiology*, **50**, 684–687.

Bergh, U. and Ekblom, B. (1979). Influence of muscle temperature on maximal muscle strength and power output in human skeletal muscles. *Acta Physiologica Scandinavica*, **107**, 33–37.

Berry, M.J. and McMurray, R.G. (1987). Effects of graduated compression stockings on blood lactate following an exhaustive bout of exercise. *American Journal of Physical Medicine*, **66**, 121–132.

Gandhi, D.B., Palmar, J.R., Lewis, B. and Schraibman, I.G. (1984). Clinical comparison of elastic supports for venous diseases of the lower limb. *Postgraduate Medical Journal*, **60**, 349–352.

Isaji, S., Yoshimura, K. and Amano, T. (1994). The regional skin temperature of the hand under different clothing conditions. *Annals of Physiological Anthropology*, **13**, 375–381.

Kraemer, W.J., Bush, J.A., Bauer, J.A., Triplett McBride, N.T., Paxton, N.J., Clemson, A., Koziris, L.P., Mangino, L.C., Fry, A.C. and Newton, R.U. (1996). Influence of compression garments on vertical jump performance in NCAA Division I volleyball players. *Journal of Strength and Conditioning Research*, **10**, 180–183.

Kraemer, W.J., Bush, J., Newton, R.U., Duncan, N.D., Volek, J., Denegar, C.R., Canavan, P., Johnston, J., Putukian, M. and Sebastianelli, W. (1998). Influence of a compressive garment on repetitive power output production before and after different types of muscle fatigue. *Sports Medicine, Training and Rehabilitation*, **8**, 163–184.

Kujala, U.M., Orava, S. and Jarvinen, M. (1997). Hamstring injuries: current trends in treatment and prevention. *Sports Medicine*, **23**, 397–404.

Kuster, M.S., Grob, K., Kuster, M., Wood, G.A. and Gachter, A. (1999). The benefits of wearing a compression sleeve after ACL reconstruction. *Medicine and Science in Sports and Exercise*, **31**, 368–371.

McComas, A.J. (1996). *Skeletal Muscle: Form and Function.* Champaign, IL: Human Kinetics.

O'Donnell, T.F., Rosenthal, D.A., Callow, A.D. and Ledig, B.L. (1979). Effect of compression on venous hemodynamics in postphlebitic limbs. *Journal of the American Medical Association*, **242**, 2766–2768.

Perlau, R., Frank, C. and Fick, G. (1995). The effect of elastic bandages on human knee proprioception in the uninjured population. *American Journal of Sports Medicine*, **23**, 251–255.

Sargeant, A.J. (1987). Effect of muscle temperature on leg extension force and short-term power output in humans. *European Journal of Applied Physiology and Occupational Physiology*, **56**, 693–698.

Sigel, B., Edelstein, A.L., Savitch, L., Hasty, J.H. and Felix, Jr. W.R. (1975). Type of compression for reducing venous stasis: a study of lower extremities during inactive recumbency. *Archives of Surgery*, **110**, 171–175.

Winter, D.A. (1990). *Biomechanics and Motor Control of Human Movement.* New York: Wiley.