IMPROVEMENTS IN LOWER-LIMB STRENGTH ARE ASSOCIATED WITH HIP CONTROL DURING LOAD CARRIAGE IN FEMALES

The purpose of this study was to investigate the effect of lower-limb strength on lower-limb biomechanical responses over the duration of a load carriage march. Female civilians (n=12) completed a 5 km march at 5.5 km·h^{-1} wearing a 23 kg external load before and after 10 weeks of hip-focussed training. Lower-limb 3D kinematics were acquired during the march, with lower-limb strength measures assessed prior to pre- and post-training marching tasks. Significant increases in lower-limb strength were elicited after training, alongside moderate to strong negative correlations between strength and hip adduction ($p<0.05$). Findings indicate that strength improvements are associated with the ability to control the lower limbs during dynamic load carriage tasks.

KEYWORDS: load carriage, female, lower-limb control, kinematics, strength.

INTRODUCTION: Soldiers in combat-related roles are required to carry heavy external loads and complete the same standardised employment tasks regardless of sex or stature. Females often display decreased physical strength and power compared with their male counterparts, which influence their ability to perform crucial military tasks (e.g., load carriage) (Brushøj et al., 2008; Groeller et al., 2015). If individuals do not have the capability to meet the demands of load carriage, adaptive gait strategies may be adopted, potentially increasing the risk of injury. Moderate to heavy load carriage is known to alter lower limb gait patterns (Simpson, Munro, & Steele, 2012) and joint loading responses in females. For example, load carriage has been shown to induce changes in hip adduction and knee abduction angles (Loverro, Hasselquist, & Lewis, 2019). Excessive changes in such movements alters lower-limb alignment (i.e., Q-angle) and can be indicative of poor dynamic control. Consequently, female soldiers with poor dynamic control may have impaired performance and higher than normal lower-limb injury risk when carrying military-relevant loads.

Lower-limb strength has been identified as a key physical component required for successfully undertaking load carriage tasks within military roles (Sharma, Greeves, Byers, Bennett, & Spears, 2015). Given that load carriage ability is related to an individual's absolute strength (Pandorf et al., 2003; Patterson, Roberts, Lau, & Prigg, 2005; Zatsiorsky & Kraemer, 2006), females may particularly benefit from specific training that targets the neuromuscular demands of load carriage. A program strengthening the hip joint musculature might elicit positive neuromuscular responses and positively influence lower-limb alignment and control during dynamic load carriage tasks (Baldon et al., 2012). Therefore, the purpose of this study was to investigate the effect of lower-limb strength on lower-limb biomechanical responses over the time-course of a load carriage march. It was hypothesised that; (i) 10 weeks of lower-body focussed training will improve lower-limb strength, and (ii), improvements in strength will enhance the dynamic control of the lower limbs.

METHODS: Twelve recreationally active female civilians (age 21.1±1.9 years, height 1.65±0.06 m, mass 64.7±6 kg) representative of a military recruit population (Australian Defence Force), volunteered to participate. All provided their written informed consent to the study, which was approved by the XXXX Human Research Ethics Committee approved the study (protocol number: XXXX). No former load carriage experience was required. Participants were required to meet or exceed inclusion criteria based on the Australian Army basic fitness standards (Australian Defence Force) for female soldiers; 18-30 years old, achieve a minimum of 70 sit-ups and 21 push-ups in 2 minutes each, and a minimum of level 7.5 on a multi-stage fitness test.

In two separate laboratory sessions, a single load-carriage task equivalent to the Australian Army minimum physical employment standards for incumbents ('All Corps Standard'; 5 km at 5.5 km·h^{-1} with a 23 kg external load) (Australian Defence Force) was completed before and after the 10-week training program. The march was conducted on a force-instrumented treadmill (AMTI force-sensing tandem treadmill, MA, USA), with simultaneous three-dimensional motion capture and ground reaction force data acquired for 30 seconds at the

beginning (0 km, pre-march) and end (5 km, post-march) of the load carriage task. Hip, knee, and ankle joint angles were estimated using a generic full-body scaled OpenSim model (Rajagopal et al., 2016) from inverse kinematics, which were used to assess changes in lower-limb biomechanics. Lower-limb strength was assessed via maximal force output using a Fitness Technology Isometric Mid-Thigh Pull (IMTP) rack (FT700 Ballistic Measurement System, Fitness Technology, Adelaide, Australia), and was conducted on a portable force plate sampling at 1000 Hz (400-series, Fitness Technology, Adelaide, SA, Australia).
Participants completed a 10-week lower-limb strength training program, which targeted muscles surrounding the hip. Up to three resistance training sessions (supervised) and two load carriage training sessions (self-directed) were performed per week. Loads prescribed were based on individual participant ability and progressively increased during the 10 weeks of training. Load, distance, and speed load carriage training sessions incrementally increased. A paired samples t-test was conducted on pre- and post-training IMTP maximal force. Pearson's correlation coefficient assessed associations between IMTP, and lower-limb kinematics collected during pre- and post-training load carriage marches. Statistical significance was set at the $p < 0.05$ level. All data were analysed using Microsoft Excel 2010 (Microsoft Corporation, WA, USA) and IBM SPSS version 25 software for Windows (IBM Corp Armonk, NY, USA).

RESULTS: Absolute strength and body mass were strongly correlated before ($p<0.01$, $r=.846$) and after training ($p<0.01$, $r=.845$). IMTP maximal force output increased by 6.8% (1732 ± 225 to 1851 ± 270; $t(11) = -2.624$, $p<0.05$) after training compared to before training (Figure 1).

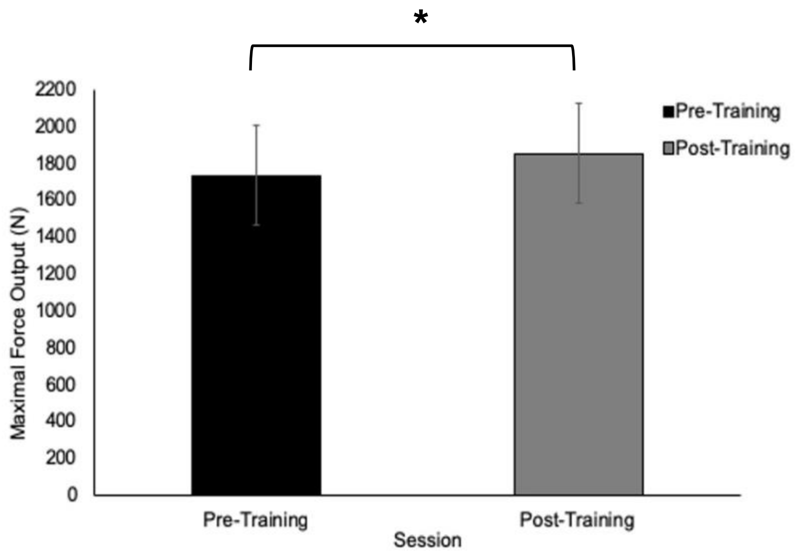

Figure 1. Pre- and Post-Training Isometric Mid-Thigh Pull maximal force output. * Indicates a significant difference between pre- and post-training tests (p<0.05).

Before training, a significant negative correlation was found between IMTP maximal force output and peak hip adduction angle during for the pre-march measurement ($r = -.599$, $p<0.05$), but not during the post-march measurement ($r = -.472$, $p>0.05$) (Figure 2A and 2B).

After training, a significant (p>0.05) negative correlation was found between IMTP maximal force output and peak hip adduction angle during loaded marching (Figure 2C and 2D). Hip adduction values at the pre-march demonstrated a strong association (r =-.803, p<0.05), and the post-march measure showed a moderate association (r =-.696, p<0.05).

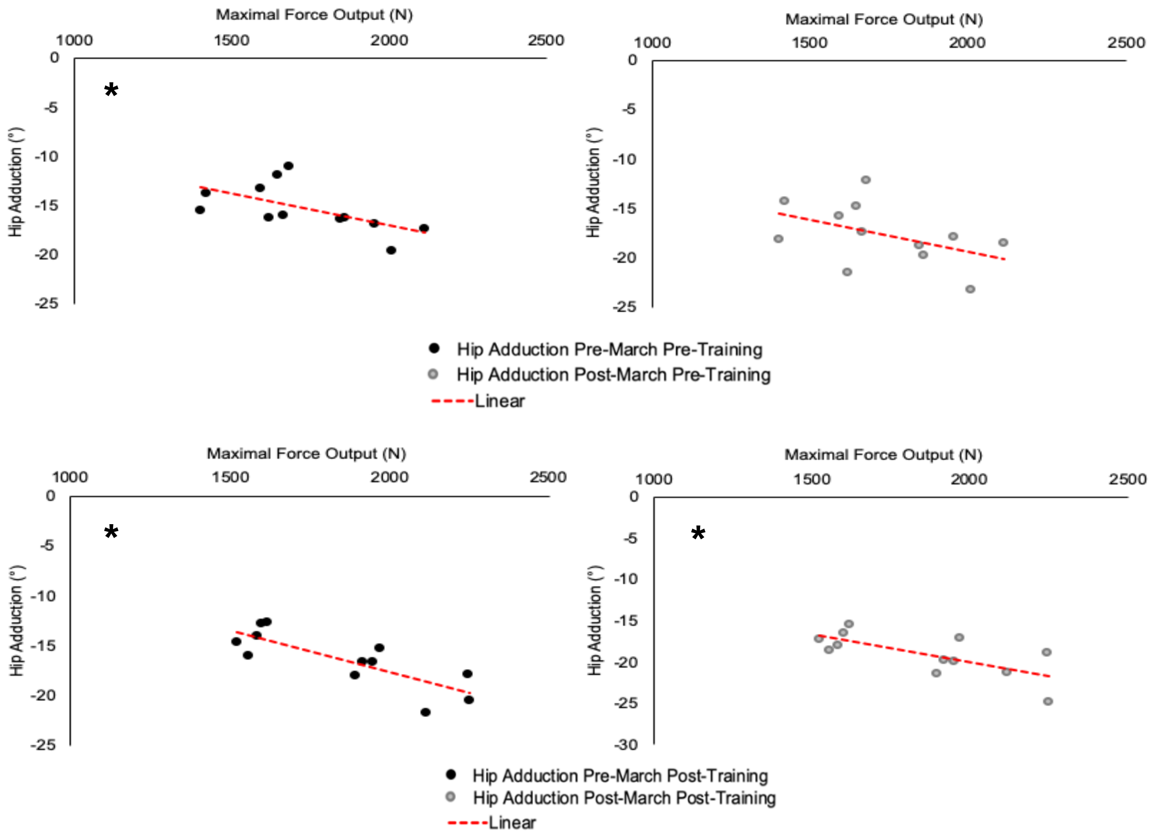

Figure 2. Correlation between Isometric Mid-Thigh Pull maximal force output and hip adduction. A) Hip adduction pre-march, pre-training, B) Hip adduction post-march, pre-training, C) Hip adduction pre-march, post-training, D) Hip adduction post-march, post-training. * Indicates a significant correlation (p<0.05).

DISCUSSION: The purpose of this study was to investigate the effect of lower-limb strength on lower-limb biomechanical responses over the time-course of a load carriage march. Lower-limb strength significantly increased after training and significant correlations were found between IMTP maximal force output and frontal plane hip kinematics. Associations suggest lower-limb strength is important in maintaining hip control during load carriage marching tasks. Improvements in IMTP measures after training demonstrates an enhanced capacity of the lower limbs to produced maximal force, which was a goal of the current training program. IMTP lower-body strength significantly correlated with peak hip adduction. However, before training, it appears that hip control decreased over the march duration (0-5 km), as evidenced by the lack of correlation observed at the post-march measure. A decreased capacity to control movement under external load during dynamic tasks (i.e., load carriage) is suggested to increase the risk of injury through increased joint loading (i.e., tibiofemoral or patellofemoral joint) (Baldon et al., 2012). Comparatively, after training, moderate to strong correlations were found for pre-post hip adduction measures. These findings indicate that as strength increased so did the ability to maintain hip adduction angle over the duration of the loaded march which may be an indicator of improved joint control.

As observed in previous work, the specificity of the current study (i.e., hip-focussed resistance training and load carriage training) may have enhanced limb coordination and overall efficiency of movement patterns (Beattie, Kenny, Lyons, & Carson, 2014). Consequently, improvements in overall mechanical efficiency (Balsalobre-Fernández, Santos-Concejero, & Grivas, 2016;

Støren, Helgerud, Støa, & Hoff, 2008) may have translated towards an enhanced capacity to meet load carriage task demands.

CONCLUSION: Results indicate that improved lower-limb strength is strongly associated with hip adduction angle, which may suggest an improved ability to control the lower limb kinematics during dynamic load carriage tasks in females. Moreover, the current results confirm the effectiveness of a 10-week specific training program can improve lower-limb strength, which may assist military organisations to successfully integrate females into physically demanding combat-related roles.

REFERENCES

Baldon, R. d. M., Lobato, D. F. M., Carvalho, L. P., Wun, P. Y. L., Santiago, P. R. P., & Serrao, F. V. (2012). Effect of Functional Stabilization Training on Lower Limb Biomechanics in Women. Medicine & Science in Sports & Exercise, 44(1), 135-145.

Balsalobre-Fernández, C., Santos-Concejero, J., & Grivas, G. V. (2016). Effects of Strength Training on Running Economy in Highly Trained Runners: A Systematic Review with Meta-Analysis of Controlled Trials. The Journal of Strength & Conditioning Research, 30(8), 2361-2368.

Beattie, K., Kenny, I. C., Lyons, M., & Carson, B. P. (2014). The Effect of Strength Training on Performance in Endurance Athletes. Sports Medicine, 44(6), 845-865.

Brushøj, C., Larsen, K., Albrecht-Beste, E., Bachmann Nielsen, M., Løye, F., & Hölmich, P. (2008). Prevention of Overuse Injuries by a Concurrent Exercise Program in Subjects Exposed to an Increase in Training Load. American Journal of Sports Medicine, 36(4), 663-670.

Australian Defence Force. The Army Physical Training Continuum. Retrieved from https://content.defencejobs.gov.au/pdf/army/Army_Physical_Continuum_Information.pdf

Groeller, H., Burley, S., Orchard, P., Sampson, J., Billing, D., & Linnane, D. (2015). How Effective Is Initial Military-Specific Training in the Development of Physical Performance of Soldiers? Journal of Strength and Conditioning Research, 29(11), S158–S162.

Loverro, K. L., Hasselquist, L., & Lewis, C. L. (2019). Females and males use different hip and knee mechanics in response to symmetric military-relevant loads. Journal of Biomechanics, 95, 109280.

Pandorf, C. E., Nindl, B. C., Montain, S. J., Castellani, J. W., Frykman, P. N., Leone, C. D., & Harman, E. A. (2003). Reliability assessment of two militarily relevant occupational physical performance tests. Canadian Journal of Applied Physiology, 28(1), 27-37.

Patterson, M., Roberts, W., Lau, W., & Prigg, S. (2005). Gender and Physical Training Effects on Soldier Physical Competencies and Physiological Strain (DSTO-TR-1875). Retrieved from Defence Science and Technology Organisation.:

Rajagopal, A., Dembia, C. L., DeMers, M. S., Delp, D. D., Hicks, J. L., & Delp, S. L. (2016). Full-Body Musculoskeletal Model for Muscle-Driven Simulation of Human Gait. IEEE Transactions on Bio-medical Engineering, 63(10), 2068-2079.

Sharma, J., Greeves, J., Byers, M., Bennett, A., & Spears, I. (2015). Musculoskeletal injuries in British Army recruits: a prospective study of diagnosis-specific incidence and rehabilitation times. *BMC Musculoskeletal Disorder, 4*(16), 106.

Simpson, K., Munro, B., & Steele, J. (2012). Effects of prolonged load carriage on ground reaction forces, lower limb kinematics and spatio-temporal parameters in female recreational hikers. Ergonomics, 55(3), 316-326.

Støren, Ø., Helgerud, J., Støa, E. M., & Hoff, J. (2008). Maximal Strength Training Improves Running Economy in Distance Runners. Medicine & Science in Sports & Exercise, 40(6), 1087-1092.

Zatsiorsky, V., & Kraemer, W. (2006). Science and Practice of Strength Training (2 ed.). Champaign, IL, US: Human Kinetics.

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