GROUND REACTION FORCES DURING PHYSICAL TRAINING IN MILITARY RECRUITS

Susan Collins, Richard Jones and Michael Llewellyn
DERA Centre for Human Sciences, Farnborough, GU14 0LX, UK

Ground reaction forces were measured as 8 healthy subjects performed 5 movements representative of military physical training. Movements comprised walk, run, 180^o cutting manoeuvre, counter-movement jump, and landing from a 0.85m drop-jump. Maximum vertical and medial forces occurred during landing from drop-jumps. Maximum lateral force and the greatest medio-lateral asymmetry occurred during cutting manoeuvres. The rate of limb loading was greatest during running. Typically these forces occurred during the initial phase of limb loading. Gym-based training, such as the 20-metre shuttle run, form a major element of Service fitness training and testing. The results suggest that such activities stress the lower limbs more than outdoor activities such as marching and drill, or the field-based elements more common during the latter stages of recruit training.

KEY WORDS: musculoskeletal Injury, gymnasium, military, GRF, dynamic movements

INTRODUCTION: Musculoskeletal injuries (MSI) frequently occur in individuals participating in fitness training, amateur and professional athletics, and in military personnel engaged in vigorous and repeated impact exercise. Whilst the need to have physically fit personnel is vital to the Armed Forces, the costs associated with the treatment and lost working time of personnel who suffer MSI as a consequence of their training is enormous. In the British Armed Forces MSI of the lower limbs and back have an average incidence of 36.8% (Neely, 1998). The injuries occur in all three services, but predominate in the Army because of the greater numbers of personnel in training. MSI of the ankle are especially common. In 1996/1997 medical attendance's within the British Army for MSI ran at a rate of 28-30 per 1000 recruits with an impact on the Army of 50 days lost per 1000 personnel per month during the period January to December 1997 (DGAMS, 1998). MSI tend to occur with greater frequency (2-3 fold) in the Training Establishments than in the field Army. For other nations the problem is similar. The incidence of soft-tissue/MSI among US Marine Corps recruits undergoing basic training is 6.6 per 1000 recruit-days representing significant clinical morbidity (Linenger & West, 1992). As a consequence, there is understandable interest in preventing MSI occurring in the Armed Forces. This study is the first phase of a project that is seeking to quantify the biomechanical risks associated with the various training activities undertaken by Armed Forces recruits. Many of the physical activities performed by Armed Forces personnel involve repetitive limb loading as a result of drill, marching or running. Often the loads acting on the limbs as a result of these activities are exacerbated by the requirement to carry pack loads that may reach 70% or more of body weight, and to operate over uneven terrain and at night. During a 5 km run some 3000 impacts occur between the lower limbs and the ground (Shorten & Winslow, 1992). Whilst a limb in normal alignment may withstand this repeated loading, an unusual pattern of foot strike, abnormal pronation during stance phase, or other abnormality may predispose the individual to injury (Cavanagh & Lafortune, 1980). The rate at which a force is applied to the limb is also an important factor in injury, since the period of 'impact absorption' (Lees, 1981) may last only a fraction of a second. Together, the magnitude of force, the number of loading cycles and the rate of loading within each cycle will determine whether the strain on the skeletal system is excessive (Crossley *et al*, 1999). To date no investigations have attempted to determine the overall contribution of a range of limb-loading impacts on overall injury risk in a specific population undergoing formalised physical strength and endurance training.

MATERIALS AND METHODS: Eight, healthy, civilian subjects (mean age 20 (1SD= 0.72) yr., height 1.78 (0.11) m, weight 78.44 (12.94) kg) participated in the study. All subjects were right-side motor dominant. Activities were performed in a gait laboratory with a floor-mounted force plate (Kistler 9281B). Force data were recorded into an analogue digital converter

(Peak Motus, ADIU) at a sample rate of 1000 Hz per channel. Subjects were investigated individually and wore shorts and a light T-shirt but no footwear. Each subject performed 10 repetitions of each of the 5 different movements, in randomised order. In all cases forces were recorded as the right foot impacted on the force plate. The 5 movements performed by each subject were: i) walking, ii) running iii) a cutting manoeuvre (Cut) performed at an angle of 180º to the approach, iv) a counter-movement (volitional jump upwards from the floor), and v) a landing (onto both feet) from a voluntary drop-jump to the floor from a height of 0.85 m. All activities were performed at subject-selected speeds. Captured data was exported from Peak Motus as ASCII code into a spreadsheet (Microsoft Excel). Within the spreadsheet data from each repetition were time-normalised prior to ensemble averaging (Winter, 1983). Ensemble averaging was performed as follows. The start and end of each impact event was identified from the vertical component of force. Using data interpolation the samples within this window were represented as 50 data points. To allow comparisons of forces recorded from subjects of different mass, the magnitude of force was divided by the individual's body weight to give normalised force (N kg^{-1}). Using these normalised data sets, averages and standard deviation values could be calculated from the 50 (normalised) data points which now represented each repetition of each activity performed by each subject. This done, intra- and inter-subject comparisons were possible and graphical representation of time-histories and of specific maxima and minima, and the statistical analysis of the data was straightforward. A one-way, repeated measures Analysis of Variance was used to determine significance, at the 95% confidence interval. The average rate of loading was calculated from the initial impact peak (not necessarily the same as maximum Ground Reaction Forces (GRF)) divided by the time taken to reach this peak, and also the maximum and minimum GRF were obtained.

RESULTS: Figure 1 shows the mean magnitude of the maximum vertical component of the GRF recorded during each of the 5 movements. The mean peak vertical GRF during the drop-jump was 54.8 (15.2) N kg^{-1}. This was significantly greater than the vertical GRF recorded as subjects performed any of the other four movements ($p<0.05$)

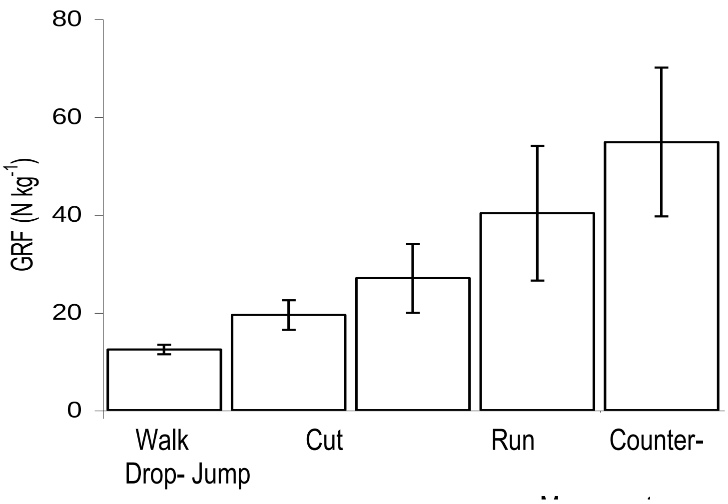

Figure 1 - A graph showing the mean magnitude of vertical component of GRF for each of the five movements in eight subjects. (Error bars show ± 1SD)

The cut produced a lower vertical GRF than running (19.46 (3.0) N kg^{-1} compared with 26.97 (7.03) N kg^{-1}. Figure 2 shows the mean of the maximum medial (+ve) and lateral (-ve) component of the reaction forces recorded during each of the 5 movements. The drop-jump gave rise to the greatest medial (2.12 (0.74) N kg^{-1} forces, which were significantly greater than the medial forces for the run, walk and cut ($p<0.05$), though not significantly greater than the counter-movement ($p>0.05$).

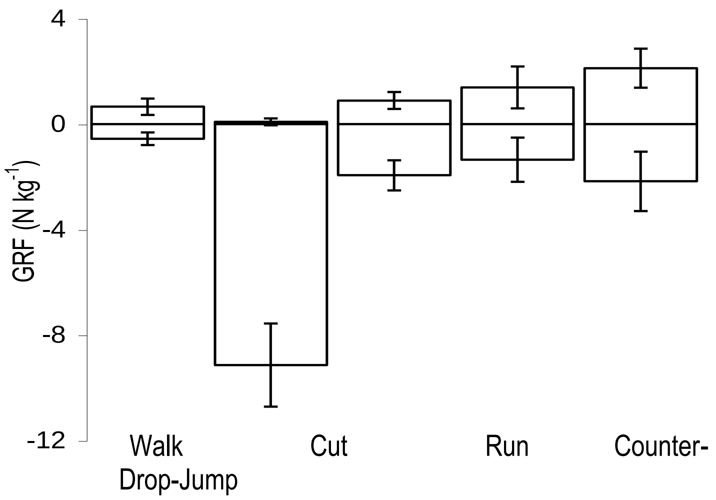

Figure 2 - A graph showing the mean magnitude of medial (+ve) and lateral (-ve) components of GRF for each of the five movements in eight subjects.
(Error bars show ± 1SD)

There is significant asymmetry of medio-lateral force in the cut with 95% of the force acting in the lateral direction (9.14 (1.58) N kg^{-1}). In the running activity there is also asymmetry with around 65-70% in the lateral direction (1.94 (0.57) N kg^{-1}) compared with the lower medial component (0.89 (0.32) N kg^{-1}). The other three activities, however, show symmetry of force in the medio-lateral direction. The rate at which force is applied to the limb under each of these conditions is summarised in Table 1. In addition to high magnitudes of force (Figure 1) the rate of loading during landings were high, since loading occurred in less than 70 ms (Table 1, Column 3). The highest rate of loading was seen during running (617 N kg^{-1} s^{-1}), an activity in which the average maximum vertical force (26.97 N kg^{-1} - see Figure 1) was the median in terms of the 5 movements.

Table 1 The Mean Vertical Rate of Loading for Each of the Five Movements in the Sample Population

Activity	**Rate of Loading (N kg^{-1} s^{-1})**	*Impact peak GRF (N kg^{-1})*	*Time to reach impact force (ms)*
Running	**617**	*16.23*	*26*
Drop-Jump	**454**	*31.12*	*69*
Counter-Movement	**383**	*29.14*	*76*
180^o Cut	**226**	*11.34*	*50*
Walking	**93**	*11.92*	*128*

The forces generated during walking are much reduced both in their magnitude (Figure 1) their medio-lateral asymmetry (Figure 2) and their rate of loading on the limb (Table 1) compared with all other activities. During walking the average vertical GRF (12.42   (0.98) N kg-1), medial GRF (0.66 (0.31) N kg^{-1}), and lateral GRF (0.56 (0.24) N kg^{-1}) were lower than for the other 4 movements.

DISCUSSION: As expected, the magnitude of the vertical component of force reflects changes in the acceleration of the mass of the body on impact; hence running produces a greater vertical components of force than does walking. Despite being voluntary in nature, landings from the drop-jump, and those arising from the counter-movement jump, were associated with the highest vertical component of force. The data on forces during the cut are more limited although it has been described as the most hazardous dynamic situation for the ligaments of the knee (Andrews *et al*, 1977). The rate at which forces are applied to the limb revealed clear differences between the activities and, given that rate of loading can be used as a measure of the shock absorbing capacity of a system, indicates perhaps where the system is at greatest risk of failure. On the basis that the greater the rate of loading is more likely to lead to injury, running and the drop-jump are the activities which carry the greatest risk, even though the actual magnitude of force during running appeared relatively innocuous. If training activities involve a large frequent running and landing from jumps, these results suggest that the provision of insoles or some other mechanism to control the rate of loading might be beneficial in terms of reducing the risk of acute or chronic MSI. With the exception of the cut, the medio-lateral component of force is relatively small. Both the magnitude, and the asymmetry of the lateral component of force are of some concern, since they expose the ankle to high moments of force that attempt to invert the ankle. The stresses applied to the limb during change-of-direction are also potentially dangerous to the knee joint (McLean et al. 1999).

CONCLUSION: This study has identified some activities that can be considered as having a higher injury risk during training of British Army recruits. These specific activities can be viewed as contributing factors to the high incidence of MSI. Although the activities analysed in this study are representative of those performed to varying degrees during the initial stages of military training, they do not represent every type of movement. The study highlights that particular attention should be paid to activities in which rapid accelerations act on the limbs since it is here that forces are maximal and greater force, or forces that are applied inappropriately, are associated with an increased risk of injury. From the perspective of military training we plan to extend this study to a wider group of subjects. We hope that by combining force data with an estimate of the total number of impacts of each type that a recruit is likely to encounter during training and correlating this with injury records a numerical score that quantifies the biomechanical risk associated with each stage of training can be developed, and used to suggest how injuries during training can be avoided.

REFERENCES:

Andrews, J.R., McLeod, W.D., Ward, T., & Howard, K. (1977). The Cutting Mechanism. *American Journal of Sports Medicine*, **5**,111-121.

Cavanagh,P.R., & Lafortune,M.A. (1980). Ground Reaction Forces in Distance Running. *Journal of Biomechanics,* **3**, 397-406.

Crossley, K., Bennell, K.L., Wrigley, T., & Oakes, B.W. (1999). Ground Reaction Forces, Bone Characteristics, and Tibial Stress Fracture in Male Runners. *Medicine and Science in Sports and Exercise,* **31**,1088-1093.

DGAMS (1998). *Annual Report on the Health of the Army*, 1996-1997.

Lees, A. (1981). Methods of Impact Absorption when Landing from a Jump*. Engineering in Medicine,* **10**, 207-211.

Lineger, J.M., & West L.A. (1992) Epidemiology of Soft-tissue Musculoskeletal Injury among United States Marine Recruits undergoing Basic Training. *Mil Med.,* **157**, 491-493.

McLean, S.G., Neal, R.J., Myers, P.T., & Walters, M.R. (1999) Knee Joint Kinematics During the Sidestep Cutting Manoeuvre: Potential for Injury in Women. *Medicine and Sciences in Sport and Exercise,* **31**, 959-967.

Neely, F.G.(1998). Intrinsic Risk Factors for Lower Limb Injuries. *Sports Medicine*. **26**, 253-263.

Shorten, M.R., & Winslow, D.S. (1992). Spectral Analysis of Impact Shock during Running. *International Journal of Sport Biomechanics,* **8**, 288-304.

Winter, D.A. (1983). *The Biomechanics and Motor Control of Human Movement*. University of Waterloo Press.

Acknowledgements

This work was carried out as part of Technology 5 (Human Sciences & Synthetic Environments) of the MoD Corporate Research Programme.