Ergonomics, 2014
http://dx.doi.org/10.1080/00140139.2014.897374

Physical fitness improvements and occupational low-back loading – an exercise intervention study with firefighters

Tyson A.C. Beach[a], David M. Frost[a], Stuart M. McGill[b] and Jack P. Callaghan[b]*

[a]*Faculty of Kinesiology and Physical Education, University of Toronto, Toronto, Canada;* [b]*Department of Kinesiology, University of Waterloo, Waterloo, Canada*

(*Received 20 August 2013; accepted 12 February 2014*)

The impact of exercise on firefighter job performance and cardiorespiratory fitness has been studied extensively, but its effect on musculoskeletal loading remains unknown. The aim of this study was to contrast the physical fitness and low-back loading outcomes of two groups of firefighters who completed different exercise programmes. Before and after 12 weeks of exercise, subjects performed a physical fitness test battery, the Functional Movement Screen™ (FMS) and simulated job tasks during which peak L4/L5 joint compression and reaction shear forces were quantified using a dynamic biomechanical model. Subjects who exercised exhibited statistically significant improvements ($p < 0.05$) in body composition, cardiorespiratory fitness, muscular strength, power, endurance and flexibility, but FMS scores and occupational low-back loading measures were not consistently affected. Firefighters who are physically fit are better able to perform essential job duties and avoid cardiac events, but short-term improvements in physical fitness may not necessarily translate into reduced low-back injury risk.

Practitioner Summary: Firefighters must be physically fit to safely and effectively meet the demands of their work, but improvements in physical fitness alone may not necessarily reduce their low-back injury risk.

Keywords: injury prevention; biomechanics; motor behaviour

Introduction

Given the nature of their work, firefighters are encouraged to enhance and maintain their physical fitness via regular exercise. Adaptations to exercise are believed to improve their job performance capabilities, reduce the risk of cardiovascular events and prevent musculoskeletal injuries (Smith 2011). Indeed, previous studies have shown that firefighters who are more physically fit report fewer and less costly low-back injuries than do firefighters who are less physically fit (Cady et al. 1979; Cady, Thomas, and Karwasky 1985). However, the impact of exercise on biomechanical variables – particularly those associated with work-related low-back injury and pain reporting (e.g. low-back loading patterns) – has been unexplored in this population.

There are several possible ways that adaptations to exercise could reduce the likelihood of sustaining musculoskeletal injuries. Because the structure, composition and quantity of bone, ligament, tendon and skeletal muscle tissue vary in response to mechanical stimuli (Taber 1995; Cowin 1999), appropriately designed exercise could cause these tissues to adapt, thereby making them less likely to be damaged when loaded. Exercise could also impact habitual patterns of movement coordination and control by altering other inherent structural or functional (physiological and psychological) personal attributes such as the following: body segment inertial characteristics (via body composition changes); flexibility and joint mobility; mechanical, electrical and metabolic functioning of movement system components and their interactions; and perception–action response patterns. These changes could influence how individuals consciously or subconsciously interact with their environment when engaging in physical activity (Davids et al. 2003); the resulting movement strategies could modify the relationship between the imposed demands (i.e. applied musculoskeletal load) and the capacity to withstand these demands (i.e. musculoskeletal load tolerance). Viewed from this perspective, exercise could reduce musculoskeletal injury potential by eliciting adaptations that guide and shape movement behaviour in ways that increase the 'margin of safety' (McGill 2004, 2009).

To date, there have been no known attempts to study the impact that exercise adaptations have on the occupational low-back loading demands of firefighters. In athletic populations, it has been demonstrated that exercise designed to alter movement coordination and control can influence sport-related musculoskeletal loading and injury risk (Myer et al. 2007; Greska et al. 2012); however, improvements in physical fitness alone do not necessarily affect these measures (Trowbridge et al. 2005; McGinn et al. 2006; Willy and Davis 2011; Herman et al. 2012). Given that improvements in physical fitness

*Corresponding author. Email: jack.callaghan@uwaterloo.ca

can enhance athletic and occupational task performance outcomes (Myer et al. 2006, 2007; Peterson et al. 2008), it could be argued that firefighters would be best served by adopting an exercise approach that combines both movement- and fitness-related objectives. Such an approach could simultaneously enhance on-the-job performance and long-term durability.

The objective of this study was to compare physical fitness, general movement abilities and occupational low-back loading outcomes between groups of firefighters who completed one of two 12-week exercise interventions: (1) fitness-oriented programme, or (2) combined movement- and fitness-oriented programme. A third group of firefighters who maintained their current exercise regimen served as controls. It was hypothesised that the different exercise approaches would result in different fitness, movement and low-back loading adaptations. The findings could ultimately be used to justify one exercise-based low-back injury prevention approach over the other.

Methods

Subjects and group assignments

Sixty men from the Pensacola Fire Department (Pensacola, FL, USA) volunteered to participate. Subjects were free of any activity-limiting health conditions. All subjects read and signed informed consent documents that had been approved by the University of Waterloo's Office of Research Ethics, the Baptist Hospital Institutional Review Board and the City of Pensacola.

Subjects were assigned to one of three groups: fitness-oriented exercise (FIT); movement- and fitness-oriented exercise (MOV); or control (CON). To account for potential confounders, a stratification procedure was employed to ensure that the 'average' subject in each group was approximately the same height, mass and age, and that they achieved the same pre-exercise composite Functional Movement Screen™ (FMS) score.

Experimental protocol and data collection

Between three and seven days both before and after the 12-week exercise programmes, subjects completed physical fitness tests, the FMS and occupational task simulations (laboratory-based biomechanical testing). The fitness tests were performed on a separate day prior to the FMS and job task simulations.

Physical fitness testing

The order in which fitness tests were performed was randomised between subjects, but the within-subject test order remained fixed in the pre- and post-exercise data collection sessions. Tests were selected to provide an overall impression of physical fitness, and included the following.

Body composition. A registered dietician used standard callipers to make skinfold measurements (mm) from the following seven sites: (1) chest – diagonal fold, one-third of the way between upper armpit and nipple; (2) abdominal – vertical fold, 2.54 cm to the right of navel; (3) thigh – vertical fold, midway between knee cap and top of thigh; (4) triceps – vertical fold, midway between elbow and shoulder; (5) subscapular – diagonal fold, directly below shoulder blade; (6) suprailiac – diagonal fold, directly above iliac crest; (7) midaxillary – horizontal fold, directly below armpit. Total body fat percentage was estimated based on the age, mass, height, sex and sum of the above-mentioned skinfold measurements (Jackson and Pollock 1978).

Gerkin treadmill protocol. A treadmill protocol was used to gauge cardiorespiratory fitness. The test began with a 3-minute warm-up during which subjects walked on a motorised treadmill at a constant speed of 4.83 km/hr and 0% grade. After the warm-up, treadmill speed was increased to 7.24 km/hr for 60 seconds. Treadmill speed and grade were then alternately increased every minute in 0.80 km/hr and 2% increments, respectively, until subjects were unable or unwilling to continue. Total time to completion was recorded (in seconds), and maximum oxygen consumption (VO_2 max) was estimated based on equations derived by Tierney et al. (2010).

Push-ups. Subjects performed push-ups until they were unable or unwilling to continue while demonstrating proper form. Initial posture was standardised by instructing subjects to place their hands under their shoulders, and to maintain a 'firm' midsection. Any repetitions during which the elbows did not fully extend or the chest did not touch a 10- cm pad located beneath their chests were not counted. The maximum number of push-ups that could be performed continuously with proper form was recorded.

Trunk muscle endurance. Isometric trunk flexion, extension and lateral bend exertions were performed to test trunk muscle endurance. As described previously (McGill, Childs, and Liebenson 1999), exertions were performed in the prone 'plank' (flexion endurance), 'Biering-Sørensen' (extension endurance) and 'side bridge' (lateral bend endurance) positions. Subjects were instructed to maintain the isometric exertions for as long as possible, and the total time to failure was recorded (in seconds). Tests were terminated when subjects were unable or unwilling to preserve their posture after one verbal warning.

Upper body power. While seated in a Keiser® AIR250 chest press machine (Keiser Corporation, Fresno, CA, USA), subjects executed maximum-speed upper body bilateral pressing exertions at five pneumatically controlled load settings (13.6, 22.7, 31.8, 40.8 and 49.9 kg). Five trials at each load setting were performed. Approximately 10 s and 60 s rest was provided between exertions and loads, respectively. Peak power display settings were recorded (in watts) for each trial and the median value over five trials was included in the statistical analyses.

Lower body power. Using a Keiser® AIR300 squat machine (Keiser Corporation, Fresno, CA, USA), subjects executed maximum-speed bilateral squatting exertions at five pneumatically controlled load settings (18.1, 27.2, 40.8, 54.4 and 68.0 kg). Five trials at each load setting were performed. Approximately 10 s and 60 s rest was provided between exertions and loads, respectively. Peak power display settings were recorded (in watts) for each trial and the median value over five trials was included in the statistical analyses. The initial squat posture was controlled by adjusting the Keiser® machine such that knees were flexed to 90 degrees (measured using a plastic goniometer). Subjects were asked to produce maximum efforts, but were not permitted to jump.

Vertical jump. As a global measure of whole-body coordination and external power output, subjects performed a maximum-effort vertical jump test. Maximum standing bilateral reach height was first recorded, and the maximum jump height was obtained using a Vertec Vertical-Jump Tester (Gill Athletics, Champaign, IL, USA). The maximum height achieved (in centimetres) among three counter-movement jump trials was recorded. Full recovery was permitted between jumps, and vanes of the Vertec device were not reset between jumps for motivational purposes.

Grip strength. Right- and left-hand grip strength was measured by instructing subjects to maximally squeeze a hand dynamometer. Tests were performed in a seated position (90 degrees of knee flexion), with arms vertically oriented and the test-side elbow flexed to 90 degrees. No movement was permitted, and subjects were encouraged to execute maximum ramped contractions. The peak value achieved among three trials was recorded (in kilograms) for inclusion in statistical analyses. Full recovery was provided between trials.

Sit-and-reach. Subjects performed three maximal sit-and-reach trials using a standard test box. Only measurements resulting from slow, controlled symmetrical movements were recorded (i.e. no bouncing or twisting was permitted). The maximum value achieved (in centimetres) among three trials was used in statistical analyses.

Functional movement screening

The general ability to move freely, symmetrically and without pain was appraised using the FMS. The FMS consists of seven tasks assumed to reveal general movement dysfunction and impairments (Cook 2003; Cook, Burton, and Hoogenboom 2006a, 2006b; Cook et al. 2010), and includes the following: deep squat; hurdle step; in-line lunge; shoulder mobility; active straight leg raise; trunk stability push-up; and rotary stability. The FMS was administered exactly as directed by Cook et al. (2010) by certified personnel; subjects were provided with standardised instructions and asked if they understood, before performing the tasks as instructed. No feedback pertaining to task performance was provided. Detailed descriptions of the FMS tasks can be found elsewhere (Cook, Burton, and Hoogenboom 2006a, 2006b; Cook et al. 2010).

Using two digital video cameras (Basler Inc., Exton, PA, USA), FMS task performance was recorded. The cameras were arranged perpendicularly to one another and temporally synchronised using Vicon Nexus software (Version 1.5, Vicon, Oxford, UK). FMS tasks were performed twice while facing one camera and twice while facing the opposite direction. In this way, sagittal plane videos were recorded from both the left and right sides of subjects together with posterior and anterior frontal plane views.

A four-point scoring system was used to grade FMS task performance. Scores ranged from 0 to 3, with 3 being the best score. If pain was perceived during task execution, a score of 0 was assigned. A score of 1 was assigned when the FMS task could not be performed. A score of 2 was assigned when a subject was able to perform an FMS task, but 'compensated'. And, a score of 3 was assigned when the task was performed correctly without any compensations. Where applicable, FMS tasks were performed on the left and right side. If there was a bilateral asymmetry, the lower score of the two sides was assigned. Three tasks included additional 'clearing' movements, to detect pain-provoking patterns (e.g. full spinal flexion/extension). The total (composite) FMS score was calculated by adding the scores of individual FMS tasks; the best total score that could be attained was 21. The FMS was graded in accordance with the criteria provided by Cook et al. (2010), and as such only the 'best' (i.e. highest graded) repetition of each task was included in the analyses. A single member of the research team with nine years of FMS experience conducted all grading using the videos recorded. The FMS can be reliably graded in this way (Minick et al. 2010; Gribble et al. 2013).

Occupational task simulations and biomechanical analyses

In a laboratory setting, subjects performed job task simulations designed to represent those performed at the fire station (i.e. general manual handling activities) and during fireground operations (e.g. structural fire suppression). General manual handing simulations consisted of lifting, pushing and pulling tasks, whereas simulated fireground duties consisted of ceiling breach, ceiling pull, forcible entry, overhead chop and hose pull tasks. When performing the fireground tasks, a weighted vest (22.7 kg) was worn to simulate the mass of a self-contained breathing apparatus and turnout gear. Subjects were asked to perform three repetitions of all tasks 'naturally' at a self-selected pace. Job task simulations included the following.

Symmetrical lift. From a relaxed upright standing posture, subjects were asked to bend forward, grasp and lift a 24.7- kg crate from the floor directly in front of them.

Asymmetrical lift. Subjects were asked to lift a 24.7- kg crate that was positioned on the floor at approximately 45 degrees with respect to the mid-sagittal plane. Initial foot position was not strictly controlled.

Unilateral push. With their feet arranged in a split-stance configuration on the force platforms (i.e. left foot forward, right foot back), subjects were asked to perform a resisted pushing motion with their right arm. A handle, attached in-series to a pneumatic cable resistance machine (Keiser® Functional Trainer, Keiser Corporation, Fresno, CA, USA), was held in the right hand at the right side of the body, pushed directly forward until the right elbow was fully extended, and then returned to the starting position. Measured cable resistance was 96 N.

Unilateral pull. A resisted right-handed pulling motion was also performed with the feet arranged in the same split-stance configuration. With their right elbow fully extended, subjects grasped the handle with their right hand, pulled the cable directly to their right side, and then returned to the starting position. Measured cable resistance was 133 N.

Ceiling breach. Subjects simulated the act of breaking through a ceiling to inspect for fire extension by pushing a pike pole overhead against resistance. Resistance was applied through a pneumatically controlled system of cable and pulleys. Measured cable resistance was 135 N.

Ceiling pull. To simulate the act of removing ceiling to check for fire extension, a pike pole was pulled downward against resistance. Measured cable resistance was 219 N.

Forcible entry. Intended to simulate the act of entering a building through a lodged door or wall, subjects struck a heavy bag five times consecutively with a 4.5- kg sledgehammer.

Overhead chop. Also using the 4.5- kg sledgehammer, subjects simulated the act of infiltrating a structure by chopping downward five times from an overhead position.

Hose pull. A rope, connected to the pneumatic resistance cable machine, was pulled by the subjects in a hand-over-hand fashion to simulate pulling a charged hose. Measured cable resistance was 133 N.

To measure body segment kinematics during job task simulations, clusters of four or five reflective markers were attached to the forearms, upper arms, head, trunk, pelvis, thighs, shanks and feet. Additional markers were taped to medial and lateral segment endpoints during a static calibration trial to generate anatomically meaningful segment-fixed coordinate systems using Visual3D™ software (Version 4, C-Motion, Inc., Germantown, MD, USA). Interactive forces and moments between the feet and ground were measured at a rate of 2400 Hz using four force platforms (Bertec Corporation, Columbus, OH, USA), and marker positions were sampled at a rate of 160 Hz using a 10-camera Vicon motion capture system (Vicon, Oxford, UK). Vicon Nexus software (Version 1.5, Vicon, Oxford, UK) was used to synchronise (spatially and temporally), capture and store the marker position and force platform data for post-processing.

Using Visual3D™, marker position data were padded (via endpoint reflection) and low-pass filtered (dual-pass, second-order Butterworth, 6- Hz cut-off) before being used to construct a 'bottom-up' inverse dynamical linked-segment model of the body. Briefly, net inter-segmental reaction kinetics were estimated by 'sectioning' the joints of the body and solving the Newton–Euler equations of motion iteratively (i.e. segment-by-segment in the proximal direction) until reaching the L4/L5 joint. Body segment mass-inertial parameters included in the inverse dynamics analyses were derived based on the default procedures in Visual3D™. Orthogonal components of the net L4/L5 joint moment were subsequently input into a polynomial equation (McGill, Norman, and Cholewicki 1996) to produce estimates of the L4/L5 'bone-on-bone' compression force. Peak L4/L5 joint compression and reaction shear forces were extracted from each trial, and averaged across for each task to provide a stable measure of peak low-back loading. The procedures used to quantify low-back loading in this study have been described in more detail previously (Beach, Frost, and Callaghan 2014; Beach et al. 2013).

Exercise programmes

The exercise programmes were designed using an undulating periodisation model wherein exercise volumes, intensities and frequencies were varied systematically across days, weeks and months (c.f. Peterson et al. 2008; Prestes et al. 2009). In both programmes, three 1.5-hour exercise sessions were scheduled each week, on non-consecutive days, and were administered by accredited strength and conditioning coaches who had over two years of coaching experience and graduate degrees in Exercise Science. As described in more detail below, the selection, order and progression of exercises differed between the FIT and MOV programmes, as did the emphasis of coaching instruction and feedback.

The primary objective of the FIT programme was to elicit maximal improvements in physical fitness over the course of 12 weeks (Table 1). Exercise technique was monitored for safety purposes, but there was minimal instruction or feedback provided pertaining to the coordination and control of body posture and motion. The FIT coach relied primarily on motivation and encouragement to maximise fitness gains. Exercise intensities were individualised based on the ability of subjects to complete the prescribed number of sets, repetitions or times. In some cases, the FIT coach made minor programme modifications (e.g. exercise additions/substitutions) if a particular subject was not progressing or if an exercise was deemed too advanced.

The MOV coach also attempted to elicit maximum improvements in physical fitness, but did so while emphasising (through instruction and feedback) the importance of *how* exercises were performed. This was done to 'stabilise' key postural and motion characteristics that have been demonstrated or hypothesised to reduce injury potential. For example, when executing squatting, lunging and jumping movements, some individuals are unable or choose not to prevent frontal plane knee motion (Ford, Myer, and Hewett 2003; Cortes et al. 2007; Hughes, Watkins, and Owen 2008). Left unchecked, this type of movement pattern could limit acute performance outcomes (e.g. weight lifted), subsequent improvements in physical fitness (e.g. strength) and increase the potential for musculoskeletal injury due to a progressive weakening of vulnerable tissues (via reduced load tolerance). Similarly, when performing upper-body pushing and pulling tasks, individuals may be unable or elect not to control the position and orientation of the lumbar spine and scapulae. It was hypothesised that if firefighters were coached *how* to move in training, 'spine-sparing' movement behaviours (McGill 2004, 2009) would emerge when executing the simulated firefighting tasks following the intervention. That is, firefighters would move their bodies in ways that reduced the low-back loading demands and/or increased the load-bearing tolerance of the spinal tissues.

Instruction and feedback guidelines followed by the MOV coach were based largely on research results and clinical observations (Sahrmann 2002, 2011; Hewett et al. 2007; McGill 2007; Myer et al. 2008; Kendall, Kendall McCreary, and Provance 2005). However, writings of prominent exercise professionals (Cook 2003; Cook et al. 2010; Verstegen and Williams 2004, 2006; Boyle 2004, 2010) were also considered given that the aforementioned research and clinical observations have been incorporated into their guidelines for exercise prescription and progression. Since it was not feasible to provide personalised exercise recommendations, the MOV programme was generically designed to address the most common movement-related deficiencies and limitations exhibited by athletes and patients. Particular emphasis was placed on static and dynamic postural control of the lumbar spine, hips and shoulder complex during exercise execution, and joint mobility exercises were included to address commonly observed limitations (e.g. rotation through the hips, thoracic spine and ankles). Though a general template was followed by all MOV subjects (Table 2), individualised instruction and

Table 1. The FIT programme template.

		Phase 1				Phase 2				Phase 3			
Day 1		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12
1A.	Trap bar deadlift	3 × 8	3 × 8	3 × 8	2 × 5	3 × 6	3 × 6	3 × 6	2 × 4	4 × 6	4 × 6	4 × 6	2 × 4
1B.	Lat pull-down/pull-up	3 × 8	3 × 8	3 × 8	2 × 5	3 × 6	3 × 6	3 × 6	2 × 4	4 × 6	4 × 6	4 × 6	2 × 4
1C.	Bench press	3 × 8	3 × 8	3 × 8	2 × 5	3 × 6	3 × 6	3 × 6	2 × 4	4 × 6	4 × 6	4 × 6	2 × 4
	Rest: 60 s between sets												
2A.	Military press	2 × 10	2 × 10	2 × 10	1 × 6	3 × 10	3 × 10	3 × 10	2 × 6	3 × 8	3 × 8	3 × 8	2 × 5
2B.	Bent over row	2 × 10	2 × 10	2 × 10	1 × 6	3 × 10	3 × 10	3 × 10	2 × 6	3 × 8	3 × 8	3 × 8	2 × 5
2C.	Single leg squat	2 × 10	2 × 10	2 × 10	1 × 6	3 × 10	3 × 10	3 × 10	2 × 6	3 × 8	3 × 8	3 × 8	2 × 5
	Rest: 30 s between sets												
3A.	Machine leg extension	2 × 15	2 × 15	2 × 15	1 × 15	2 × 10	2 × 10	2 × 10	1 × 10	2 × 8	2 × 8	2 × 8	1 × 8
3B.	Machine hamstring curl	2 × 15	2 × 15	2 × 15	1 × 15	2 × 10	2 × 10	2 × 10	1 × 10	2 × 8	2 × 8	2 × 8	1 × 8
3C.	Abdominal curl-up	2 × 15	2 × 15	2 × 15	1 × 15	2 × 10	2 × 10	2 × 10	1 × 10	2 × 8	2 × 8	2 × 8	1 × 8
	Rest: 30 s between sets												
Cardio (run, bike, versa)		30 min low intensity				30 min low intensity				30 min low intensity			
Day 2		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12
1A.	Squat-to-press	2 × 15	2 × 15	2 × 20	1 × 12	2 × 25	2 × 25	2 × 30	1 × 20	2 × 35	2 × 35	2 × 40	1 × 25
1B.	Horizontal pull-up	2 × 15	2 × 15	2 × 20	1 × 12	2 × 25	2 × 25	2 × 30	1 × 20	2 × 35	2 × 35	2 × 40	1 × 25
1C.	Medicine ball slam	2 × 15	2 × 15	2 × 20	1 × 12	2 × 25	2 × 25	2 × 30	1 × 20	2 × 35	2 × 35	2 × 40	1 × 25
	Rest: 45 s between sets												
2A.	Push-up	2 × 15	2 × 15	2 × 20	1 × 12	2 × 25	2 × 25	2 × 30	1 × 20	2 × 35	2 × 35	2 × 40	1 × 25
2B.	Lunge walk	2 × 15	2 × 15	2 × 20	1 × 12	2 × 25	2 × 25	2 × 30	1 × 20	2 × 35	2 × 35	2 × 40	1 × 25
2C.	Medicine ball rotation	2 × 15	2 × 15	2 × 20	1 × 12	2 × 25	2 × 25	2 × 30	1 × 20	2 × 35	2 × 35	2 × 40	1 × 25
	Rest: 45 s between sets												
3A.	Grip (squeeze)	2 × 15	2 × 15	2 × 20	1 × 12	2 × 25	2 × 25	2 × 30	1 × 20	2 × 35	2 × 35	2 × 40	1 × 25
3B.	Wrist roll	2 × 15	2 × 15	2 × 20	1 × 12	2 × 25	2 × 25	2 × 30	1 × 20	2 × 35	2 × 35	2 × 40	1 × 25
3C.	Exercise ball crunch	2 × 15	2 × 15	2 × 20	1 × 12	2 × 25	2 × 25	2 × 30	1 × 20	2 × 35	2 × 35	2 × 40	1 × 25
	Rest: 45 s between sets												
Cardio (run, bike, versa)		30 min med intensity (work: rest−6:1 to 1:1)				30 min med intensity (work: rest−6:1 to 1:1)				30 min med intensity (work: rest−6:1 to 1:1)			
Day 3		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12
1A.	Seated leg press	2 × 30 s	2 × 30 s	2 × 30 s	1 × 30 s	3 × 30 s	3 × 30 s	3 × 30 s	2 × 30 s	3 × 45 s	3 × 45 s	3 × 45 s	2 × 30 s
1B.	Seated chest press	2 × 30 s	2 × 30 s	2 × 30 s	1 × 30 s	3 × 30 s	3 × 30 s	3 × 30 s	2 × 30 s	3 × 45 s	3 × 45 s	3 × 45 s	2 × 30 s
1C.	Cable row	2 × 30 s	2 × 30 s	2 × 30 s	1 × 30 s	3 × 30 s	3 × 30 s	3 × 30 s	2 × 30 s	3 × 45 s	3 × 45 s	3 × 45 s	2 × 30 s
	Rest: 45 s between sets												
2A.	Machine squat	2 × 30 s	2 × 30 s	2 × 30 s	1 × 30 s	2 × 45 s	2 × 45 s	2 × 45 s	1 × 45 s	2 × 45 s	2 × 45 s	2 × 45 s	1 × 45 s
2B.	Machine shoulder press	2 × 30 s	2 × 30 s	2 × 30 s	1 × 30 s	2 × 45 s	2 × 45 s	2 × 45 s	1 × 45 s	2 × 45 s	2 × 45 s	2 × 45 s	1 × 45 s
2C.	V-pulls	2 × 30 s	2 × 30 s	2 × 30 s	1 × 30 s	2 × 45 s	2 × 45 s	2 × 45 s	1 × 45 s	2 × 45 s	2 × 45 s	2 × 45 s	1 × 45 s
	Rest: 45 s Between sets												
3A.	Biceps curl	2 × 30 s	2 × 30 s	2 × 30 s	1 × 30 s	2 × 45 s	2 × 45 s	2 × 45 s	1 × 45 s	2 × 60 s	2 × 60 s	2 × 60 s	1 × 60 s
3B.	Triceps extension	2 × 30 s	2 × 30 s	2 × 30 s	1 × 30 s	2 × 45 s	2 × 45 s	2 × 45 s	1 × 45 s	2 × 60 s	2 × 60 s	2 × 60 s	1 × 60 s
3C.	Side plank	2 × 30 s	2 × 30 s	2 × 30 s	1 × 30 s	2 × 45 s	2 × 45 s	2 × 45 s	1 × 45 s	2 × 60 s	2 × 60 s	2 × 60 s	1 × 60 s
	Rest: 45 s between sets												
Cardio (run, bike, versa)		30 min high intensity (work: rest−1:1 to 1:6)				30 min high intensity (work: rest−1:1 to 1:6)				30 min high intensity (work: rest−1:1 to 1:6)			

Notes: Exercises labelled with the same number (e.g. 1A, 1B and 1C) were performed in succession prior to completing a second set. During the first three weeks of each phase, the FIT coach modified training intensities such that the desired number of repetitions could be achieved with a maximal effort. The fourth week in each phase was treated as an active recovery week (i.e. the volume of loading was halved while maintaining intensity).

Table 2. The MOV programme template.

		Phase 1		Phase 2				Phase 3				Phase 4	
Day 1		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12
1A.	Single Arm bench press	3 × 8	3 × 8	3 × 12	3 × 12	3 × 12	3 × 12	4 × 15	4 × 15	4 × 15	4 × 15	3 × 8	3 × 8
1B.	ROM exercise	N/A	N/A	3 × 5	3 × 5	3 × 5	3 × 5	3 × 5	3 × 5	3 × 5	3 × 5	3 × 5	3 × 5
1C.	Single Leg RDL	3 × 8	3 × 8	3 × 12	3 × 12	3 × 12	3 × 12	4 × 12	4 × 12	4 × 12	4 × 12	3 × 8	3 × 8
1D.	ROM exercise	N/A	N/A	N/A	N/A	N/A	N/A	3 × 8	3 × 8	3 × 8	3 × 8	3 × 5	3 × 5
	Rest: 45 s between sets												
2A.	Cable lift/chop	3 × 8	3 × 8	3 × 12	3 × 12	3 × 12	3 × 12	N/A	N/A	N/A	N/A	3 × 6	3 × 6
2B.	ROM exercise	2 × 6	2 × 6	2 × 5	2 × 5	2 × 5	2 × 5	N/A	N/A	N/A	N/A	2 × 5	2 × 5
	Rest: 45 s between sets												
3A.	Single Arm military press	3 × 8	3 × 8	3 × 12	3 × 12	3 × 12	3 × 12	3 × 12	3 × 12	3 × 12	3 × 12	2 × 9	2 × 9
3B.	Supine hamstring curl	3 × 8	3 × 8	3 × 12	3 × 12	3 × 12	3 × 12	3 × 12	3 × 12	3 × 12	3 × 12	2 × 9	2 × 9
	Rest: 45 s between sets												
Cardio (run, bike, elliptical)		30 min med intensity (low, mod and high HR)		30 min med intensity (low and high HR)				30 min med intensity (low, mod and high HR)				30 min med intensity (low, mod and high HR)	
Day 2		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12
1A.	Elevated split squat	3 × 8	3 × 8	3 × 10	3 × 10	3 × 10	3 × 12	4 × 12	4 × 12	4 × 12	4 × 12	3 × 6	3 × 6
1B.	ROM exercise	N/A	N/A	3 × 5	3 × 5	3 × 5	3 × 5	3 × 6	3 × 6	3 × 6	3 × 6	3 × 5	3 × 5
1C.	Lat pull-down/pull-up	3 × 8	3 × 8	3 × 10	3 × 10	3 × 10	3 × 10	4 × 12	4 × 12	4 × 12	4 × 12	3 × 6	3 × 6
1D.	ROM exercise	N/A	N/A	N/A	N/A	N/A	N/A	3 × 6	3 × 6	3 × 6	3 × 6	3 × 5	3 × 5
	Rest: 45 s between sets												
2A.	Cable chop/lift	3 × 8	3 × 8	3 × 10	3 × 10	3 × 10	3 × 10	N/A	N/A	N/A	N/A	2 × 6	2 × 6
2B.	ROM exercise	2 × 6	2 × 6	2 × 8	2 × 8	2 × 8	2 × 8	N/A	N/A	N/A	N/A	2 × 6	2 × 6
	Rest: 45 s between sets												
3A.	Forward lunge	3 × 8	3 × 8	3 × 10	3 × 10	3 × 10	3 × 10	3 × 12	3 × 12	3 × 12	3 × 12	2 × 7	2 × 7
3B.	Single Arm bent-over row	3 × 8	3 × 8	3 × 10	3 × 10	3 × 10	3 × 10	3 × 12	3 × 12	3 × 12	3 × 12	2 × 7	2 × 7
	Rest: 45 s between sets												
Cardio (run, bike, elliptical)		30 min low intensity (low and mod HR)		30 min low intensity (low and mod HR)				30 min low intensity (low and mod HR)				30 min low intensity (low, mod and high HR)	
Day 3		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12
1A.	Squat-to-press	3 × 10	3 × 10	3 × 10	3 × 10	3 × 10	3 × 10	4 × 10	4 × 10	4 × 10	4 × 10	3 × 6	3 × 6
1B.	ROM exercise	N/A	N/A	3 × 5	3 × 5	3 × 5	3 × 5	3 × 6	3 × 6	3 × 6	3 × 6	3 × 5	3 × 5
1C.	RDL-to-row	3 × 10	3 × 10	3 × 8	3 × 8	3 × 8	3 × 8	4 × 10	4 × 10	4 × 10	4 × 10	3 × 6	3 × 6
1D.	ROM exercise	N/A	N/A	3 × 5	3 × 5	3 × 5	3 × 5	3 × 6	3 × 6	3 × 6	3 × 6	3 × 5	3 × 5
	Rest: 45 s between sets												
2A.	Cable push/pull	3 × 10	3 × 10	3 × 8	3 × 8	3 × 8	3 × 8	N/A	N/A	N/A	N/A	3 × 6	3 × 6
2B.	ROM exercise	2 × 6	2 × 6	2 × 5	2 × 5	2 × 5	2 × 5	N/A	N/A	N/A	N/A	2 × 8	2 × 8
	Rest: 45 s between sets												
3A.	Lateral lunge	3 × 8	3 × 8	3 × 8	3 × 8	3 × 8	3 × 8	3 × 12	3 × 12	3 × 12	3 × 12	2 × 7	2 × 7
3B.	Pullover-to-extension	3 × 8	3 × 8	3 × 8	3 × 8	3 × 8	3 × 8	3 × 12	3 × 12	3 × 12	3 × 12	2 × 7	2 × 7
	Rest: 45 s between sets												
Cardio (run, bike, elliptical)		30 min high intensity (low, mod and high HR)		30 min high intensity (low and high HR)				30 min high intensity (low, mod and high HR)				30 min high intensity (low and high HR)	

Notes: Exercises labelled with the same number (e.g. 1A, 1B and 1C) were performed in succession prior to completing a second set. Range of motion (ROM) activities included various low-intensity flexibility/mobility (e.g. hamstring stretch) exercises. The MOV coach modified training intensities such that the desired number of repetitions could be achieved with a maximal effort. Where applicable, exercises were progressed from unilateral to bilateral over the 12 weeks. The intensity of each cardio training session was monitored using heart rates as measured during their baseline fitness test.

feedback were provided by the coach. More specifically, the MOV coach was instructed to visually inspect for any 'weak links' (i.e. uncontrolled movements) in the kinetic chain and was to base instruction and feedback on observations made. Guidelines followed for visual observation are summarised in Appendix 1. When subjects were able to perform the assigned number of repetitions, the intensity of an exercise was progressed until uncontrolled movements emerged. Essentially, visually observable patterns of movement coordination and control functioned as a compass to guide exercise prescription and progression within the general MOV programme template.

A minimum level of compliance for data inclusion was set *a priori* at 30/36 training sessions over the 12 weeks. CON subjects were asked to maintain their normal routine for 12 weeks prior to post-testing.

Statistical analyses

The impact of exercise on measures of physical fitness and low-back loading was tested using general linear models with one between-subject factor (group) and one within-subject factor (time). Mean values of the fitness and low-back loading measures calculated across trials formed the dependent variables in the statistical analyses. Given the study objectives, the primary undertaking was to identify any statistically significant group × time interaction effects (i.e. $p < 0.05$), though the 'direction' of any changes was certainly of interest. Accordingly, when group × time interaction effects were statistically significant, a least-square means procedure with adjustments for multiple comparisons, via the Tukey method, was used. The influence of exercise on FMS scores was examined using Wilcoxon signed-rank tests. All statistical analyses were performed using SAS system software (Windows Version 9.1.3 with Service Pack 4, SAS Institute Inc., Cary, NC, USA).

Results

Three subjects voluntarily withdrew from the study and one subject was unable to attend 83% of the exercise sessions. Equipment malfunction resulted in loss of biomechanical data for an additional two subjects. Included in the results are data from the subjects from whom full data sets were obtained (CON = 16 subjects; FIT = 18 subjects; MOV = 20 subjects).

Physical fitness test scores

As summarised in Table 3, FIT and MOV subjects exhibited statistically significant improvements in nearly all measures of physical fitness. With the exception of minor changes in upper body strength, power and endurance, the physical fitness of CON subjects remained relatively stable over 12 weeks.

Functional Movement Screen™ scores

When the data were pooled, FMS task scores in the FIT and MOV groups were not different between the pre- and post-exercise testing sessions (Table 4); however, upon closer inspection of the individual data sets it was revealed that FMS scores were variable (i.e. individual scores increased, decreased and remained the same) (Table 5). This finding made it difficult to determine whether exercise resulted in consistent changes in movement qualities purported to be measured by the FMS. Interpretation was particularly complicated by the finding that CON subject FMS scores were also not stable over the study duration.

Low-back loading demands during occupational task simulations

Although some pre- to post-exercise differences in peak L4/L5 joint compression and reaction shear forces were detected, there was no clear indication that either programme induced 'spine-sparing' adaptations in movement behaviour. In only one task (hose pull) was the pre-to-post change in peak L4/L5 joint compression for FIT and MOV subjects different from those in the CON group (Table 6). Between the pre- and post-exercise testing sessions, peak L4/L5 compression was not different in the CON group ($p = 0.968$), significantly lower in magnitude amongst MOV subjects ($p = 0.001$) and higher for FIT ($p = 0.004$). In the other tasks where pre- to post-exercise differences in peak L4/L5 compression were detected (symmetrical lift, unilateral push, ceiling pull), the MOV, FIT and CON groups responded similarly.

In only two tasks (asymmetrical lift, symmetrical lift) were the pre- to post-exercise responses in peak L4/L5 reaction shear forces different between CON, FIT and MOV subjects. When performing asymmetrical lifts, MOV subjects experienced lower peak L4/L5 A/P reaction shear forces post-exercise ($p = 0.022$), whereas no changes were noted amongst the CON ($p = 0.068$) or FIT ($p = 0.591$) groups (Table 7). In contrast, while performing the symmetric lifts, no pre- to post-exercise differences in peak L4/L5 M/L reaction shear forces were detected in the FIT ($p = 0.249$) or MOV ($p = 0.060$) groups, but the CON subjects experienced an increase post-exercise ($p = 0.028$) (Table 8). In other tasks

Table 3. Summary of physical fitness results for subjects in the control group (CON), fitness-oriented exercise group (FIT) and movement- and fitness-oriented exercise group (MOV).

	CON		FIT		MOV		p-value[a]		
Physical fitness measure	Pre	Post	Pre	Post	Pre	Post	Group	Time	Group × Time
Body mass (kg)	93.0 (3.9)	92.7 (3.9)	95.1 (3.0)	94.7 (2.9)	94.8 (3.1)	95.0 (2.8)	0.878	0.523	0.745
Body fat (%)	18.7 (1.8)	18.9 (1.8)	18.5 (1.8)	17.1 (1.5)	16.8 (1.8)	15.4 (1.4)	–	–	0.041
Treadmill time (s)	663 (24.3)	640 (21.7)	665 (30.3)	749 (25.2)	640 (26.2)	703 (25.5)	–	–	<0.001
Predicted $V0_2$ max	39.4 (1.33)	38.4 (1.18)	38.8 (1.63)	42.9 (1.45)	38.5 (1.35)	41.4 (1.27)	–	–	<0.001
Trunk flexion endurance (s)	80.4 (13.6)	86.0 (11.5)	75.9 (10.8)	133.9 (11.5)	91.2 (12.7)	134.0 (11.4)	–	–	0.001
Trunk extension endurance (s)	89.9 (9.7)	83.9 (9.0)	73.0 (4.8)	118.3 (8.9)	94.5 (10.9)	126.9 (10.1)	–	–	<0.001
Trunk right lateral bend endurance (s)	51.4 (6.6)	47.4 (3.8)	54.8 (7.3)	68.5 (3.7)	68.7 (9.5)	62.7 (4.3)	0.108	0.845	0.230
Trunk left lateral bend endurance (s)	65.4 (9.2)	54.6 (5.2)	53.6 (5.6)	78.4 (5.0)	65.2 (7.4)	74.3 (3.9)	–	–	0.011
Push-ups (#)	39.1 (3.4)	43.6 (3.2)	39.4 (4.2)	65.5 (5.0)	36.8 (3.4)	50.3 (4.1)	–	–	<0.001
Keiser chest press @ 30 lb (W)	315 (9.7)	330 (11.8)	322 (12.6)	364 (17.4)	317 (11.2)	332 (14.7)	–	–	0.039
Keiser chest press @ 50 lb (W)	375 (12.1)	381 (15.2)	408 (20.7)	416 (15.1)	372 (17.6)	386 (18.9)	0.276	0.068	0.779
Keiser chest press @ 70 lb (W)	407 (16.5)	408 (16.4)	435 (30.4)	447 (20.4)	384 (22.2)	418 (24.5)	0.397	0.038	0.154
Keiser chest press @ 90 lb (W)	408 (17.6)	414 (20.3)	423 (28.5)	456 (23.5)	393 (24.8)	434 (34.0)	0.695	0.002	0.168
Keiser chest press @ 110 lb (W)	387 (20.2)	383 (22.3)	400 (30.9)	445 (25.8)	362 (28.7)	408 (38.3)	–	–	0.031
Vertical jump (cm)	54.3 (2.1)	54.8 (1.9)	53.9 (2.4)	57.0 (2.2)	54.1 (2.3)	56.7 (2.2)	–	–	0.037
Keiser squat @ 40 lb (W)	187 (10.2)	219 (12.0)	196 (12.9)	301 (13.1)	199 (11.2)	250 (15.0)	–	–	0.002
Keiser squat @ 60 lb (W)	347 (16.3)	376 (17.1)	374 (17.7)	470 (18.3)	359 (18.0)	425 (19.2)	–	–	0.043
Keiser squat @ 90 lb (W)	602 (24.0)	617 (18.6)	619 (21.6)	745 (24.7)	614 (29.1)	692 (29.3)	–	–	0.003
Keiser squat @ 120 lb (W)	832 (28.6)	861 (27.5)	865 (27.5)	1035 (29.0)	827 (33.9)	952 (32.9)	–	–	<0.001
Keiser squat @ 150 lb (W)	1064 (34.6)	1082 (31.0)	1090 (30.8)	1269 (35.6)	1045 (44.8)	1170 (41.4)	–	–	<0.001
Right grip strength (kg)	46.6 (1.7)	48.3 (1.5)	48.0 (1.3)	49.7 (1.1)	46.6 (1.8)	48.8 (1.8)	0.731	0.001	0.799
Left grip strength (kg)	45.8 (1.7)	47.6 (1.6)	45.4 (1.2)	47.4 (1.0)	44.7 (1.9)	46.7 (1.9)	0.999	<0.001	0.986
Sit-and-reach (cm)	21.2 (2.4)	19.7 (2.0)	22.0 (1.9)	21.7 (1.9)	20.2 (2.1)	24.4 (1.5)	–	–	<0.001

[a]General linear model ANOVAs with one between-subject factor (group: CON vs. FIT vs. MOV) and one within-subject factor (time: pre vs. post) were performed to examine the impact of exercise on physical fitness measures.

Table 4. Mean (SEM) scores of FMS tasks performed at the beginning (pre) and end (post) of the study.

	CON			FIT			MOV		
FMS task[a]	Pre	Post	*p*-value[b]	Pre	Post	*p*-value[b]	Pre	Post	*p*-value[b]
ASLR	1.8 (0.17)	2.0 (0.16)	0.398	1.6 (0.14)	1.6 (0.14)	1.000	1.8 (0.14)	1.9 (0.15)	0.688
HSTP	1.9 (0.08)	1.9 (0.09)	1.000	2.0 (0.00)	2.0 (0.00)	1.000	2.0 (0.05)	1.8 (0.11)	0.500
ILNG	2.1 (0.13)	2.3 (0.09)	0.750	2.4 (0.11)	2.5 (0.12)	0.625	2.1 (0.15)	2.3 (0.17)	0.438
PSHP	2.0 (0.19)	1.8 (0.12)	0.217	1.8 (0.20)	1.7 (0.17)	0.670	1.9 (0.20)	1.7 (0.17)	0.398
RTRY	2.0 (0.17)	1.8 (0.14)	0.484	2.0 (0.15)	2.3 (0.13)	0.172	1.8 (0.14)	1.9 (0.15)	0.563
SHLD	1.7 (0.18)	2.2 (0.13)	0.048	1.6 (0.17)	1.8 (0.19)	0.359	1.8 (0.19)	1.8 (0.20)	1.000
DSQT	1.3 (0.13)	1.2 (0.08)	0.531	1.4 (0.16)	1.1 (0.07)	0.125	1.4 (0.14)	1.2 (0.17)	0.375
COMP	12.5 (0.54)	12.8 (0.46)	0.662	12.8 (0.41)	13.1 (0.44)	0.396	12.8 (0.62)	12.6 (0.52)	0.888

Note: Data from control group (CON), fitness-oriented exercise group (FIT) and fitness- and movement-oriented exercise group (MOV) subjects are included.
[a]ASLR = active straight-leg raise; HSTP = hurdle step; ILNG = in-line lunge; PSHP = push-up; RTRY = rotary stability; SHLD = shoulder mobility; DSQT = deep squat; COMP = composite (total) FMS score.
[b]Wilcoxon signed-rank tests were used to make within-group (pre–post) comparisons in FMS scores.

Table 5. Number of subjects whose FMS scores increased (↑), decreased (↓) or did not change (–) over the study duration.

	CON			FIT			MOV		
FMS task[a]	↑	↓	–	↑	↓	–	↑	↓	–
ASLR	4	2	10	5	6	7	4	2	14
HSTP	1	2	13	0	0	18	0	2	18
ILNG	1	1	14	3	1	14	5	2	13
PSHP	1	6	9	6	4	8	3	5	12
RTRY	3	6	7	6	2	10	5	2	13
SHLD	9	3	4	5	2	11	5	2	13
DSQT	1	3	12	1	6	11	1	3	16
COMP	8	6	2	9	5	4	8	5	7

Note: Data from control group (CON), fitness-oriented exercise group (FIT) and fitness- and movement-oriented exercise group (MOV) subjects are included.
[a]ASLR = active straight-leg raise; HSTP = hurdle step; ILNG = in-line lunge; PSHP = push-up; RTRY = rotary stability; SHLD = shoulder mobility; DSQT = deep squat; COMP = composite (total) FMS score.

Table 6. Mean (SEM) peak L4/L5 compression forces (kN) quantified during the performance of laboratory-simulated tasks performed at the beginning (pre) and end (post) of the study.

	CON		FIT		MOV		*p*-value[b]		
Task[a]	Pre	Post	Pre	Post	Pre	Post	Group	Time	Group × Time
ASYM	7.57 (0.38)	7.58 (0.42)	7.53 (0.26)	7.60 (0.30)	7.55 (0.31)	7.54 (0.30)	0.998	0.880	0.969
SYMM	6.95 (0.33)	7.21 (0.32)	7.34 (0.21)	7.61 (0.29)	7.25 (0.29)	7.45 (0.29)	0.598	0.041	0.959
PUSH	2.06 (0.10)	2.26 (0.13)	2.23 (0.10)	2.40 (0.17)	2.04 (0.13)	2.28 (0.15)	0.583	0.004	0.911
PULL	3.22 (0.18)	3.49 (0.32)	3.03 (0.14)	3.29 (0.20)	3.16 (0.21)	3.14 (0.21)	0.751	0.134	0.467
CBRC	3.70 (0.38)	3.79 (0.42)	4.32 (0.40)	4.30 (0.28)	4.81 (0.34)	5.11 (0.32)	0.023	0.732	0.606
CPUL	2.83 (0.29)	2.57 (0.24)	3.14 (0.23)	2.75 (0.17)	3.09 (0.20)	3.00 (0.23)	0.460	0.005	0.371
FENT	12.8 (1.15)	12.9 (1.21)	12.8 (0.94)	13.5 (0.90)	12.6 (1.03)	13.1 (1.06)	0.968	0.118	0.732
CHOP	7.65 (0.61)	7.43 (0.49)	7.76 (0.39)	7.80 (0.40)	7.13 (0.42)	7.58 (0.44)	0.773	0.612	0.312
HPUL	5.10 (0.34)	5.09 (0.41)	4.34 (0.23)	4.99 (0.35)	5.09 (0.47)	4.66 (0.34)	–	–	0.003

Note: Data from control group (CON), fitness-oriented exercise group (FIT) and fitness- and movement-oriented exercise group (MOV) subjects are included.
[a]ASYM = asymmetrical lift; SYMM = symmetrical lift; PUSH = unilateral push; PULL = unilateral pull; CBRC = ceiling breach; CPUL = ceiling pull; FENT = forcible entry; CHOP = overhead chop; HPUL = hose pull.
[b]General linear model ANOVAs with one between-subject factor (group: CON vs. FIT vs. MOV) and one within-subject factor (time: pre vs. post) were performed to examine the impact of exercise on peak L4/L5 compression forces during task execution.

Table 7. Mean (SEM) peak L4/L5 anterior/posterior reaction shear forces (*N*) quantified during the performance of laboratory-simulated tasks performed at the beginning (pre) and end (post) of the study.

	CON		FIT		MOV		*p*-value[b]		
Task[a]	Pre	Post	Pre	Post	Pre	Post	Group	Time	Group × Time
ASYM	371 (36.9)	420 (39.3)	322 (29.0)	335 (31.4)	371 (24.0)	318 (25.0)	–	–	0.014
SYMM	339 (32.3)	358 (35.3)	291 (29.6)	288 (25.7)	311 (24.9)	310 (34.6)	0.332	0.754	0.844
PUSH	112 (6.4)	112 (7.0)	119 (10.7)	115 (8.6)	129 (11.5)	118 (9.4)	0.608	0.376	0.693
PULL	227 (12.1)	243 (12.4)	232 (17.3)	224 (10.6)	230 (13.5)	224 (11.3)	0.855	0.930	0.409
CBRC	195 (13.8)	188 (19.1)	218 (18.5)	199 (15.6)	209 (17.3)	230 (26.9)	0.348	0.661	0.294
CPUL	222 (16.6)	204 (10.6)	235 (13.0)	212 (9.1)	246 (16.5)	232 (17.0)	0.333	0.035	0.883
FENT	232 (19.9)	227 (31.6)	227 (19.9)	239 (24.0)	269 (23.1)	240 (22.7)	0.674	0.435	0.235
CHOP	731 (46.2)	745 (38.8)	711 (36.4)	738 (37.7)	749 (38.7)	743 (28.5)	0.897	0.577	0.788
HPUL	325 (23.6)	296 (26.3)	264 (23.5)	248 (20.9)	261 (23.2)	241 (17.3)	0.090	0.068	0.908

Note: Data from control group (CON), fitness-oriented exercise group (FIT) and fitness- and movement-oriented exercise group (MOV) subjects are included.
[a]ASYM = asymmetrical lift; SYMM = symmetrical lift; PUSH = unilateral push; PULL = unilateral pull; CBRC = ceiling breach; CPUL = ceiling pull; FENT = forcible entry; CHOP = overhead chop; HPUL = hose pull.
[b]General linear model ANOVAs with one between-subject factor (group: CON vs. FIT vs. MOV) and one within-subject factor (time: pre vs. post) were performed to examine the impact of exercise on peak L4/L5 A/P reaction shear forces during task execution.

Table 8. Mean (SEM) peak L4/L5 medial/lateral reaction shear forces (*N*) quantified during the performance of laboratory-simulated tasks performed at the beginning (pre) and end (post) of the study.

	CON		FIT		MOV		*p*-value[b]		
Task[a]	Pre	Post	Pre	Post	Pre	Post	Group	Time	Group × Time
ASYM	125 (11.2)	147 (14.7)	96 (4.8)	94 (3.9)	100 (5.0)	99 (6.9)	< 0.001	0.184	0.082
SYMM	76 (6.3)	88 (8.9)	83 (4.5)	77 (5.1)	82 (5.6)	92 (5.8)	–	–	0.034
PUSH	87 (8.7)	80 (8.9)	74 (5.3)	73 (5.8)	67 (6.1)	62 (5.1)	0.082	0.244	0.761
PULL	152 (15.3)	146 (13.4)	121 (8.4)	113 (8.1)	117 (9.9)	111 (10.5)	0.049	0.074	0.989
CBRC	128 (8.7)	132 (15.1)	160 (10.5)	121 (8.0)	140 (14.6)	129 (11.4)	0.572	0.005	0.102
CPUL	147 (11.4)	130 (9.1)	168 (15.1)	127 (9.0)	133 (7.7)	117 (8.1)	0.163	0.001	0.222
FENT	243 (13.1)	243 (15.6)	249 (10.0)	231 (12.2)	237 (13.2)	221 (13.6)	0.665	0.101	0.519
CHOP	191 (12.6)	191 (11.8)	183 (9.9)	178 (10.8)	190 (11.5)	195 (13.0)	0.672	0.980	0.744
HPUL	174 (11.0)	161 (10.8)	155 (9.9)	155 (12.1)	168 (11.0)	150 (12.3)	0.704	0.061	0.356

Data from control group (CON), fitness-oriented exercise group (FIT), and fitness- and movement-oriented exercise group (MOV) subjects are included.
[a]ASYM = asymmetrical lift; SYMM = symmetrical lift; PUSH = unilateral push; PULL = unilateral pull; CBRC = ceiling breach; CPUL = ceiling pull; FENT = forcible entry; CHOP = overhead chop; HPUL = hose pull.
[b]General linear model ANOVAs with one between-subject factor (group: CON vs. FIT vs. MOV) and one within-subject factor (time: pre vs. post) were performed to examine the impact of exercise on peak L4/L5 M/L reaction shear forces during task execution.

where pre- to post-exercise differences in peak L4/L5 reaction shear forces were detected (ceiling breach, ceiling pull), the MOV, FIT and CON groups responded similarly.

Discussion

This study examined the notion that in comparison to a conventional fitness-oriented exercise approach (FIT), exercise designed to simultaneously meet both movement- and fitness-oriented objectives (MOV) would constitute a preferred low-back injury prevention strategy for firefighters. Specifically, it was hypothesised that firefighters who completed the MOV programme would perform simulated occupational tasks in ways that attenuated peak low-back loading demands. Although both FIT and MOV subjects exhibited significant improvements in physical fitness, it could not be concluded that either intervention consistently impacted peak low-back loading responses to simulated job demands.

Movements are ‘learned’ when desired/intended changes are retained (beyond training) and transfer to other related, yet unrehearsed activities. Motor learning can be affected by the frequency, timing and/or type of feedback provided in addition to the organisation and structure of practice (Wulf, Shea, and Lewthwaite 2010). It is certainly possible that such factors were inappropriately incorporated in the MOV programme. However, in a thorough kinematic analysis of a subset of the data reported here (Frost 2013), it was found that subjects who completed the MOV programme were more likely to exhibit less spine and frontal plane knee motion during job task simulations. Conversely, those who completed the FIT programme tended to display more spine and frontal plane knee motion post-intervention. Since low-back loading estimates in this study were based solely on measures of net L4/L5 joint reaction forces (shear) or moments (compression) without explicitly taking trunk muscle activation or lumbar posture into account, it is possible that there were changes in low-back loading that went undetected. The polynomial method was used in this study because it has been shown, on average, to produce peak low-back compression estimates that are not significantly different from those derived from more complex EMG- and optimisation-assisted spine models (Gagnon, Lariviere, and Loisel 2001); however, a more sophisticated musculoskeletal modelling approach would have likely have provided additional insight. Alternatively, it is possible that the kinematic adaptations exhibited by MOV subjects were unaccompanied by changes in low-back loading, but still 'protective' given that the load-bearing tolerance of the lumbar spine varies with posture (Gunning, Callaghan, and McGill 2001; Howarth and Callaghan 2012).

When changes in peak L4/L5 joint compression and reaction shear forces were exhibited by the 'average' MOV or FIT subject, they were either consistent with those seen in the CON group or of biomechanically trivial magnitudes (i.e. exercise did not cause average peak low-back loading levels to fall below or rise above recommended action limits for joint compression or reaction shear forces; Vieira and Kumar 2006; Gallagher and Marras 2012). However, the pooled low-back loading results did not accurately characterise the responses of all study subjects. There were CON, FIT and MOV subjects who displayed peak low-back forces of greater, lesser and equal magnitude post-exercise, and in several cases, the differences could be considered biomechanically meaningful based on the above-mentioned criteria. Due to the inter- and intra-individual variability in low-back loading responses, there was no apparent impact of exercise when the data were aggregated. Inter- and intra-individual variability is an inherent characteristic of human movement (Davids et al. 2003), attributed to the fact that the musculoskeletal linkage is endowed with numerous biomechanical degrees of freedom and thus motor task objectives can be satisfied using many different patterns of movement coordination and control. More sophisticated methods of motion analyses (e.g. Daffertshofer et al. 2004; Graham et al. 2011; Choudry et al. 2013; Preatoni et al. 2013) and single-subject experimental designs might be better suited to expose and monitor movement-related exercise adaptations (Bates 1996), especially in cases where data aggregation results in an average response that is different from those of the individual subjects (Dufek et al. 1995). Given that only three to five trials of job task simulations were collected in this study, it was not possible to implement these analyses *a posteriori*.

It is interesting to note that the FMS did not serve as a good 'transfer test' in this study. For example, though Shultz et al. (2013) indicated that the test–retest reliability of FMS scores is satisfactory if captured within a 7-day period, Frost et al. (2012) found that the pre- and post-exercise FMS scores of the CON subjects in the current study were sufficiently variable to raise concern about the ability of the FMS to detect exercise adaptations over longer time periods. Previous 6- and 7-week intervention studies used the FMS to document exercise adaptations (Goss et al. 2009; Cowen 2010; Kiesel, Plisky, and Butler 2011), but no control groups were included and individual FMS task scores were not provided (i.e. intra-individual variation in between-day FMS task scores could be 'masked' in the composite FMS score). Moreover, the parametric statistical tests employed may have led to misleading conclusions because FMS tasks are graded on an ordinal scale. Since it is possible that the FMS captures normal fluctuations in the ability to move freely, symmetrically and without pain, the time-varying nature of these qualities appears worthy as a topic for future investigation.

Although simulated occupational low-back loading demands may not decrease with improvements in physical fitness, placing emphasis on *how* exercises are to be performed could mitigate the risk of sustaining exercise-related injuries. This alone could have strong impact given that exercise-related injuries comprise a large percentage of all musculoskeletal injuries reported by fire service personnel (Bylund and Bjornstig 1999; de Loes and Jansson 2001; Poplin et al. 2012; Jahnke et al. 2013). Moreover, being more physically fit could enhance on-the-job performance (Peterson et al. 2008), reduce the likelihood of experiencing a cardiovascular event (Wynn and Hawdon 2012) and delay the onset of potentially injurious fatigue-induced movement adaptations (Dolan and Adams 1998; Cortes et al. 2012). It is also necessary to highlight that the long-term effects of exercise can impact work-related injury potential by influencing factors not measured in this study (e.g. musculoskeletal load tolerance). For this reason, firefighters who exercise could conceivably alter their 'margin of safety' at work without changing their habitual movement behaviours or low-back loading demands.

There are two important limitations that must be considered when interpreting the results. First, given the large number of dependent variables that were analysed, this study may have been statistically underpowered due to the relatively small number of subjects and trials included. Second, using a weighted vest to simulate the mass of personal protective equipment worn by firefighters likely resulted in an overestimation of the low-back loading and mechanical stability demands that would be imposed during *bona fide* fireground operations (i.e. due to the location and mass distribution of the weighted vest). Thus, the absolute low-back load magnitudes reported in this study should be interpreted with caution. These limitations notwithstanding, it is important to emphasise that a within-subject experimental design was employed to: (1)

maximise the statistical power with the number of firefighters who were willing/able to participate; and (2) make relative (pre- vs. post-exercise) comparisons in the physical fitness, general movement and low-back loading variables of interest.

Conclusions

This study tested the notion that exercise designed to elicit movement- and/or fitness-based adaptations would alter how firefighters elected to move their bodies and load their low-backs when performing simulated work tasks. Although the physical fitness of study subjects improved significantly in response to the 12-week exercise interventions, it could not be concluded that either exercise approach consistently altered simulated occupational low-back loading demands. Firefighters must be physically fit to safely and effectively meet their occupational demands, but results of this study suggest that short-term improvements in physical fitness alone are unlikely to translate into reduced low-back loading on the job without directed efforts to 'transfer' these improvements. More research is needed to better understand how individuals adapt to exercise, and what impact exercise adaptations have on movement behaviour, low-back loading and hypothesised injury potential.

Acknowledgements

The authors would like to express their gratitude to members of the Pensacola Fire Department, Athletes' Performance Institute and Andrews Research and Education Institute for their support and contribution to study design and execution. The authors would also like to thank Drs Clark Dickerson, Joan Stevenson and Philip Bigelow for their comments on earlier drafts of this manuscript.

Funding

Funding for this research was provided by the Centre of Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD). Dr Jack Callaghan is supported by the Canada Research Chair (CRC) in Spine Biomechanics and Injury Prevention.

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Appendix 1

SQUAT PATTERN – Observations and Coaching Cues

Observation	Injury/Performance Considerations
A. Lumbar spine curvature	• Flexion or extension reduces the load bearing capacity of the spine • Minimal spine motion (power) will increase the force applied to the external load`
B. Foot, knee and hip alignment	• Frontal plane knee motion can increase the load placed on the supporting ligaments • Ground reaction forces should be directed through the knee joint
C. Position of center of pressure (COP) relative to feet	• Shifting the COP towards the toe increases the external knee flexion moment, towards the heel increases the hip flexion moment • Opposite influence internally
D. Position of external load (if applicable)	• The distance between the external load (D) and each joint will influence the external and internal moments • Minimize the horizontal distance between the load and the COP (C)

Squat Pattern Exercises

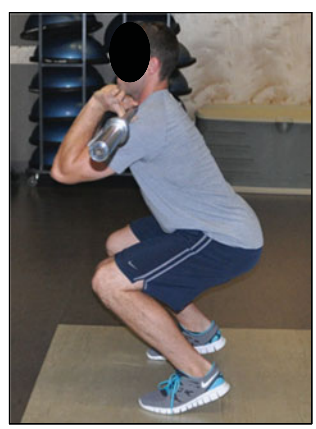
- Bodyweight squat
- Back squat
- Front squat
- Overhead squat
- Single leg squat
- Vertical jump

Common Observations to Address via Coaching

- Lumbar spine extension
- Lumbar spine flexion
- Medial collapse of knees
- Bodyweight on toes
- Bodyweight on heels

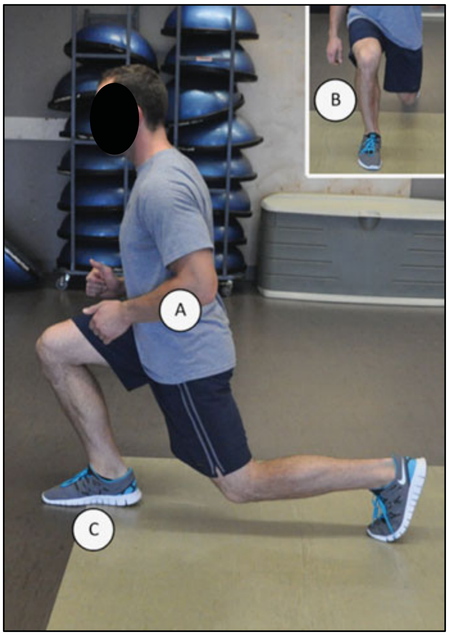
Coaching Cues

- No spine motion (resist)
- Trunk and shins parallel
- Heels and toes on ground
- Bodyweight over mid-foot
- Grip the ground with toes
- Keep barbell over mid-foot
- Hips, knees, feet aligned
- Pull down, push up



*Bodyweight on toes

LUNGE PATTERN – Observations and Coaching Cues



Observation	Injury/Performance Considerations
A. Lumbar spine curvature	• Flexion, extension and rotation reduces the load bearing capacity of the spine • Minimal spine motion (power) will increase the force applied to the external load
B. Foot, knee and hip alignment	• Frontal plane knee motion can increase the load placed on the supporting ligaments • Ground reaction forces should be directed through the knee joint
C. Position of bodyweight relative to front foot	• Shifting bodyweight towards the toe increases the external knee flexion moment, towards the heel increases the hip flexion moment • Opposite influence internally

Lunge Pattern Exercises

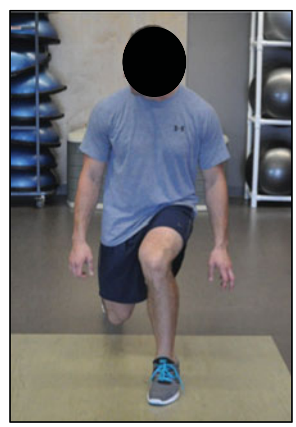
- Bodyweight lunge
- Split squat
- Back lunge
- Front lunge
- Running
- Bounding

Common Observations to Address via Coaching

- Lumbar spine extension
- Lumbar spine flexion
- Hip/spine rotation
- Medial collapse of knees
- Bodyweight on front toe

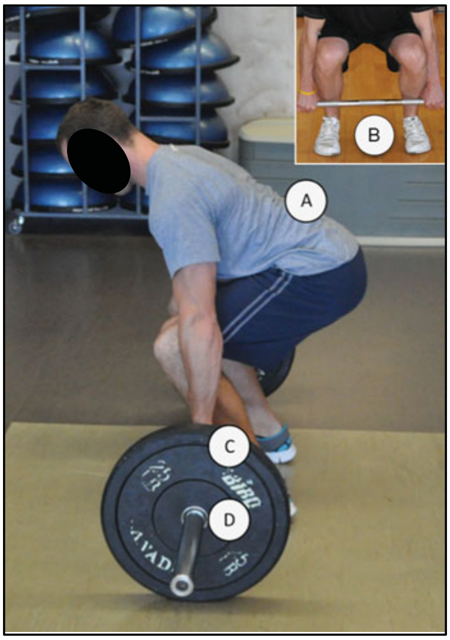
Coaching Cues

- No spine motion (resist)
- Trunk and back thigh parallel
- Front heel on ground
- Feet facing forwards
- Grip ground with front foot
- Hips, knees, feet aligned
- Pull down, push up



*Medial collapse of knee

LIFT PATTERN – Observations and Coaching Cues



Observation	Injury/Performance Considerations
A. Trunk angle versus spine curvature	• Flexion or extension of the spine reduces its load bearing capacity • Provided that spine flexion is avoided, a forward trunk lean can be an effective lifting strategy
B. Foot, knee and hip alignment	• Regardless of foot width, the hips, knees and feet should be aligned • Ground reaction forces should be directed through the knee joint
C. Position of center of pressure (COP) relative to feet	• Shifting the COP towards the toe increases the external knee flexion moment, towards the heel increases the hip flexion moment • Opposite influence internally
D. Position of external load (if applicable)	• The distance between the external load (D) and each joint will influence the external and internal moments • Minimize the horizontal distance between the load and the COP (C)

Lift Pattern Exercises

- Deadlift
- Romanian deadlift (RDL)
- Single leg RDL
- Cable lift
- Bent-over row
- RDL-to-row

Common Observations to Address via Coaching

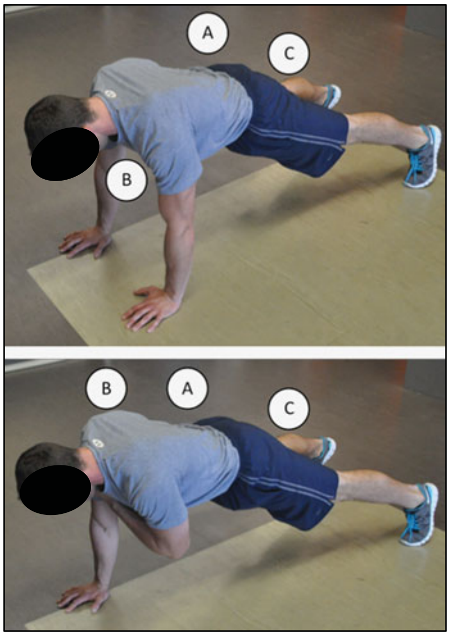
- Lumbar spine extension
- Lumbar spine flexion
- Upright torso
- Bodyweight on toes
- Shoulders posterior to load
- Load away from body

Coaching Cues

- No spine motion (resist)
- Heels and toes on ground
- Bodyweight over mid-foot
- Grip the ground with toes
- Shoulders in line with load
- Hips, knees, feet aligned
- Keep load close
- Pull down, push up

*Shoulders posterior to load

PUSH PATTERN – Observations and Coaching Cues



Observation	Injury/Performance Considerations
A. Lumbar spine curvature	• Flexion, extension and rotation reduces the load bearing capacity of the spine • Spine motion may limit any contribution from the lower body (lack of stiffness)
B. Shoulder and scapula motion	• Anterior rotation and shoulder elevation may reduce the capacity of the joint • The scapula should move with the upper limb
C. Use of lower body	• Every movement is a whole-body effort • Consider how the lower body can contribute (remain stiff, generate momentum) to every motion thought to be an upper-body effort (e.g. bench press)

Push Pattern Exercises

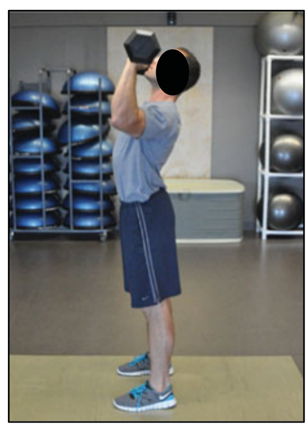
- Push-up
- Bench press
- Overhead press (military)
- Single arm push-up
- Single arm press
- Cable chop/press

Common Observations to Address via Coaching

- Lumbar spine extension
- Lumbar spine flexion
- Lumbar spine rotation
- Shoulder anterior rotation
- Shoulder elevation

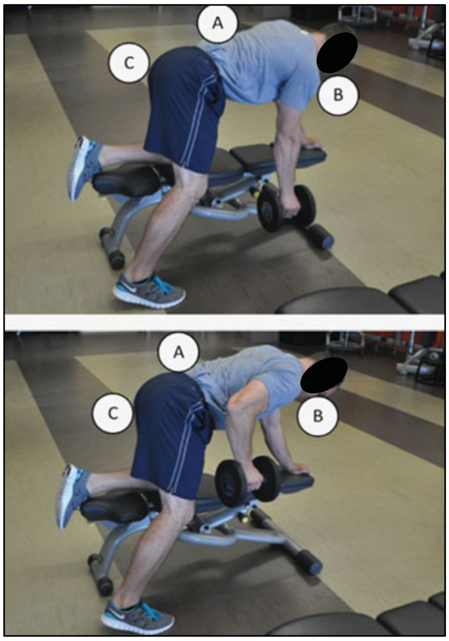
Coaching Cues

- Head and chin back
- No spine motion (resist)
- Shoulders back and down
- Allow the scapula to move
- Strong grip
- Pull load towards body
- Push body away from hands
- Use lower body



*Lumbar spine extension

PULL PATTERN – Observations and Coaching Cues



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C. Use of lower body	• Every movement is a whole-body effort • Consider how the lower body can contribute (remain stiff, generate momentum) to every motion thought to be an upper-body effort (e.g. pull-up)

Pull Pattern Exercises

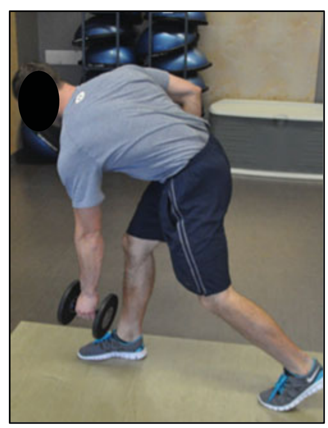
- Horizontal pull-up
- Pull-up
- Pull-down
- Bent-over row
- Cable pull
- RDL-to-row

Common Observations to Address via Coaching

- Lumbar spine extension
- Lumbar spine flexion
- Lumbar spine rotation
- Shoulder anterior rotation
- Shoulder elevation

Coaching Cues

- Head and chin back
- No spine motion (resist)
- Shoulders back and down
- Allow the scapula to move
- Strong grip
- Use lower body
- Externally rotate hands with pull



*Lumbar spine flexion/rotation