Exercise-Based Performance Enhancement and Injury Prevention for Firefighters: Contrasting the Fitness- and Movement-Related Adaptations to Two Training Methodologies

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Abstract

Frost, DM, Beach, TAC, Callaghan, JP, and McGill, SM. Exercise-based performance enhancement and injury prevention for firefighters: Contrasting the fitness- and movement-related adaptations to two training methodologies. *J Strength Cond Res* 29(9): 2441–2459, 2015—Using exercise to enhance physical fitness may have little impact on performers' movement patterns beyond the gym environment. This study examined the fitness and movement adaptations exhibited by firefighters in response to 2 training methodologies. Fifty-two firefighters were assigned to a movement-guided fitness (MOV), conventional fitness (FIT), or control (CON) group. Before and after 12 weeks of training, participants performed a fitness evaluation and laboratory-based test. Three-dimensional lumbar spine and frontal plane knee kinematics were quantified. Five whole-body tasks not included in the interventions were used to evaluate the transfer of training. FIT and MOV groups exhibited significant improvements in all aspects of fitness; however, only MOV exhibited improvements in spine and frontal plane knee motion control when performing each transfer task (effect sizes [ESs] of 0.2–1.5). FIT exhibited less controlled spine and frontal plane knee motions while squatting, lunging, pushing, and pulling (ES: 0.2–0.7). More MOV participants (43%) exhibited *only* positive posttraining changes (i.e., improved control), in comparison with FIT (30%) and CON (23%). Fewer negative posttraining changes were also noted (19, 25, and 36% for MOV, FIT, and CON). These findings suggest that placing an emphasis on *how* participants move while exercising may be an effective training strategy to elicit behavioral changes beyond the gym environment. For occupational athletes such as firefighters, soldiers, and police officers, this implies that exercise programs designed with a movement-oriented approach to periodization could have a direct impact on their safety and effectiveness by engraining desirable movement patterns that transfer to occupational tasks.

Key Words program design, learning, coaching

Introduction

Designing interventions to enhance physical fitness characteristics (e.g., muscular strength) or to change movement strategies (e.g., lifting technique) can yield successful results when the specific objectives are defined. For example, scientists have used targeted interventions to reduce the knee abduction moment in females performing a drop jump (28), alleviate patellofemoral pain in runners (31), lower spinal moments during lifting (21), and improve performance in weightlifting exercises such as the clean (35) and snatch (38). However, recent evidence has shown that improvements in strength (15) or joint range-of-motion (27) in isolation may have little influence on *how* someone performs an unrehearsed whole-body task. And even when movement-based adaptations are achieved with specific biofeedback techniques, it is not guaranteed that these changes will "transfer" to tasks that are kinematically similar (31). As a result, for the purpose of preventing musculoskeletal injuries and improving performance within populations that are exposed to highly variable task demands (e.g., athletes, firefighters, and military service personnel), it could be questioned whether conventional approaches to exercise are sufficient.

To facilitate motor learning, retention, and the transfer of training, it has been suggested that movements be performed that largely replicate the tasks of interest (2). For firefighters, this would imply that various high-risk physically demanding job tasks be simulated in a training environment. Although such an approach is logical, frequent exposure to job task simulations could elevate the firefighter's risk of injury if they lacked the requisite physical ability (e.g., strength, endurance, and aerobic capacity) or awareness (e.g., recognition of ergonomic hazards) to perform safely

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and effectively. This suggests that although improving physical fitness may be necessary, it could be insufficient to enhance performance and reduce the risk of occupational injury. As such, perhaps exercise should be considered not only as a tool to enhance performance through improvements in physical fitness but also a means to stabilize "key" kinematic features that are generalizable across a range of tasks and have been linked to a lower injury risk (e.g., frontal plane knee motion control during fireground- and gym-related activities). Viewed in this way, firefighters could then use exercise to develop the physical ability and awareness to safely and effectively meet the variable demands of their work.

Although the degree to which training transfers may be individual-, task-, and program-specific, learning to safely and effectively perform various general exercises could (in principle) influence how unrehearsed tasks are performed. In turn, this may also reduce the trainee's risk of sustaining an occupation- or exercise-related injury. However, to achieve this objective, an emphasis should likely be placed on engraining specific yet generalizable movement features that have been shown to influence joint loading [e.g., spine flexion (7) and frontal plane knee motion (16)] while exercising. It was this premise and the high prevalence of musculoskeletal injuries in the fire service that motivated this investigation. The objective was to compare fitness- and movement-related adaptations (i.e., spine and frontal plane knee motion control) between career firefighters exposed to 2 different exercise strategies. The first approach was modeled as a high-intensity exercise program focused specifically on improving physical fitness, whereas the other aimed to enhance physical fitness and movement awareness concurrently (i.e., the firefighters were discouraged through instruction and feedback from using potentially "risky" movement patterns, whereas the number of repetitions, load lifted, or set duration was progressed in a periodized fashion). The pre- and post-training spine and frontal plane knee motion were compared with 5 occupationally relevant transfer tasks that were unrehearsed during the 12-week training.

Methods

Experimental Approach to the Problem

Career firefighters completed a comprehensive fitness test and a movement evaluation, comprising a battery of whole-body tasks performed with varying loads and speeds, while instrumented for quantitative motion analysis. On completion of the 2 testing sessions, they were randomly assigned to a movement-guided fitness, fitness, or control group. Both training interventions comprised 12-week periodized exercise programs designed to improve firefighter fitness but differed most notably with regard to the attention placed on *how* each exercise was performed (kinematically). Participants attended three 1.5-hour sessions each week and were coached by the National Strength and Conditioning Association (NSCA)-accredited professionals. Within 1 week of completing the 12-week protocol, participants returned for a second fitness and movement evaluation. The battery of tasks served as transfer tests to evaluate the movement-related adaptations to training (no formal coaching or feedback was provided). Select descriptors of motion that have been previously implicated as possible mechanisms of injury were used for comparative purposes.

Subjects

Seventy-five men from the Pensacola Fire Department were recruited to participate. All men were free of musculoskeletal injury or pain at the time of testing and on full active duty. Because of the time commitment required, 15 were unable to participate in the movement evaluation and 4 withdrew before completing their 12 weeks of training. An additional 4 data sets were lost because of equipment malfunction, leaving 52 participants who completed pre- and posttesting. The mean (*SD*) age, height, body mass, and Functional Movement Screen (FMS) score of the participants completing the pre- and postfitness and movement tests are described in Table 1. The FMS is a qualitative whole-body movement–based screen that has demonstrated some efficacy in the prediction of injuries (23) and is currently being used to help guide the design of exercise programs for

Table 1. The mean (*SD*) age, height, body mass, and Functional Movement Screen score for participants completing the pre and post fitness ($N = 66$) and laboratory-based testing ($N = 52$) sessions.*

Sample	Group (N)	Age (y)	Height (m)	Body Mass (kg)	FMS score
Fitness testing	Movement (23)	39.3 (10.5)	1.81 (0.06)	89.4 (14.2)	12.9 (2.7)
	Fitness (19)	35.1 (10.0)	1.80 (0.07)	89.9 (13.2)	12.8 (1.7)
	Control (24)	38.9 (9.4)	1.79 (0.05)	92.6 (15.6)	12.9 (2.4)
Laboratory testing	Movement (21)	38.7 (10.4)	1.81 (0.06)	89.6 (14.7)	13.0 (2.8)
	Fitness (16)	35.9 (9.7)	1.80 (0.07)	91.6 (13.4)	12.4 (1.5)
	Control (15)	38.3 (9.3)	1.80 (0.06)	96.0 (15.2)	12.9 (2.9)

*The characteristics described are of each intervention group before training.

Table 2. Training adaptations for measures of general fitness as outlined in the International Association of Fire Fighters' Wellness-Fitness Initiative.*†

Group (N)	BOD (%)	TRD (s)	LPK (s)	RPK (s)	FPK (s)	EXT (s)	LGP (kg)	RGP (kg)	PSH (reps)	CMJ (cm)	SIT (cm)
Movement (23)	−1.4‡ (2.2)	62.4‡ (52.5)	9.0 (31.0)	−5.5 (42.8)	47.5‡ (30.4)	35.1‡ (33.1)	2.0‡ (3.9)	2.0‡ (4.7)	13.8‡ (8.4)	2.6‡ (3.3)	4.4‡ (4.5)
Fitness (19)	−1.3‡ (2.3)	88.6‡ (66.6)	21.2‡ (29.5)	11.1 (32.3)	63.7‡ (57.4)	50.8‡ (35.1)	1.9‡ (3.3)	1.3 (5.1)	25.6‡ (11.5)	2.6‡ (3.4)	−0.3 (4.6)
Control (24)	0.2 (1.5)	−22.6 (57.4)	−10.8 (39.0)	−4.0 (24.9)	5.6 (36.7)	−5.6 (22.4)	1.8‡ (2.6)	1.4 (4.1)	4.5‡ (7.8)	0.4 (2.5)	−1.5 (3.0)

*BOD = body composition; TRD = treadmill; LPK = left plank; RPK = right plank; FPK = front plank; EXT = Biering-Sorensen; LGP = left grip; RGP = right grip; PSH = max push-ups; CMJ = vertical jump; SIT = sit-and-reach.
†Data represent the magnitude of change (*SD*) posttraining for the participants ($N = 66$) who completed the pre- and posttraining fitness test.
‡Significant change ($p \leq 0.05$) posttraining.

athletes and firefighters (22,32). The composite FMS score was used in this study strictly as 1 factor considered in the assignment of study participants to the 3 groups before training to ensure an even distribution of scores. The University of Waterloo's Office of Research Ethics, the Baptist Hospital Institutional Review Board, and the City of Pensacola each approved the investigation, and all participants gave their informed consent before the data collection began.

Test Selection

Fitness Evaluation. In accordance with the International Association of Fire Fighters' (IAFF) Wellness and Fitness Initiative (19), 6 components of general fitness were evaluated: (a) body composition–estimated using the sum of 7 skinfolds and generalized equations for predicting body fat percentage (20); (b) aerobic capacity–estimated with the Gerkin treadmill protocol (13); (c) muscular strength–grip strength was measured with a hand dynamometer (14); (d) muscular endurance–evaluated with a combination of dynamic (i.e., maximum push-ups) and static (i.e., front plank, side plank, and Biering-Sorensen) tests (26); (e) lower-body power–estimated using countermovement jump height (19); and (f) flexibility–assessed with the modified sit-and-reach (19). The specific details of each test were described to participants using a series of standardized instructions; however, a formal familiarization protocol was not used.

Movement Evaluation. The 5 transfer tests were chosen to reflect commonly performed whole-body tasks that impose similar movement demands to those experienced by firefighters while on-duty (e.g., challenge control of spine flexion while lifting and pulling). The 5 tasks were (a) lift–from standing, a box ($0.33 \times 0.33 \times 0.28$ m) was lifted from the floor to waist height; (b) squat–a body weight squat was performed; (c) lunge–a forward lunge was performed with the right leg; (d) push–from a split stance (left leg forwards), a standing press was performed with the right arm; (e) pull–from a split stance (left leg forwards), a standing pull was performed with the right arm.

Experimental Protocol

Fitness Testing. A registered dietician recorded participants' height, body mass and conducted the skinfold assessment. The fitness test was then administered by an NSCA-accredited strength and conditioning professional using 8 standardized procedures. (a) Participants performed a graded treadmill test (13). After 3 minutes at 4.8 $km \cdot h^{-1}$ (0% grade) and 1 minute at 7.2 $km \cdot h^{-1}$ (0% grade), the speed or incline was raised every minute (0.8 $km \cdot h^{-1}$ or 2% grade) until volitional fatigue. Treadmill time was used as a surrogate of aerobic capacity. Twenty minutes of rest was given before the next test. (b) Participants performed 3 sit-and-reach trials while seated on the floor with their legs extended and feet flat against the sit-and-reach box. (c) Grip strength was measured using a hand dynamometer (Takei Kiki Kogyo, Nigata,

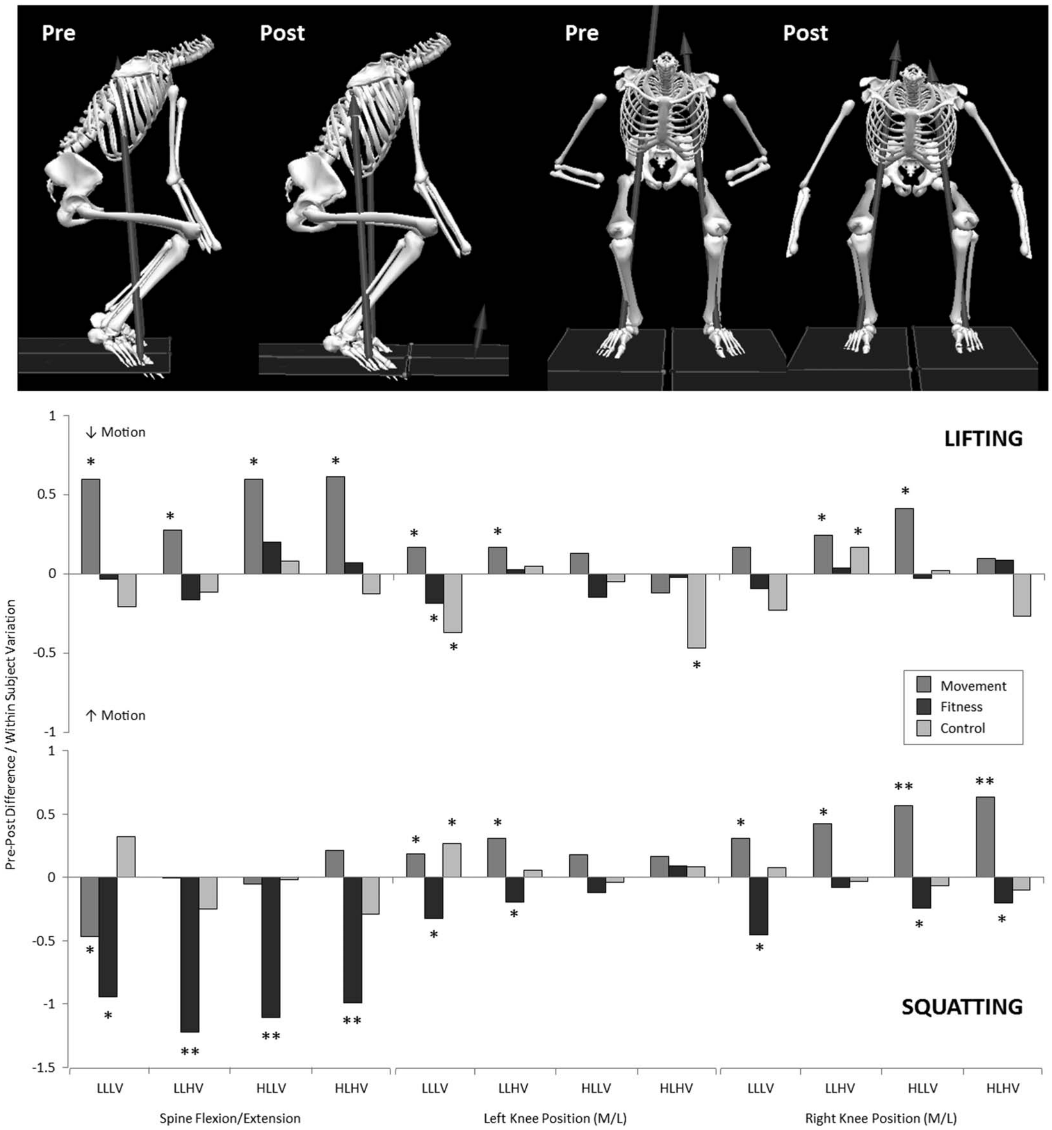

Figure 1. Lift- and squat-specific adaptations in peak spine and knee motion for each condition (load × speed) and group. Changes are presented as a function of the maximum within-subject variation + 1*SD* and depict those exhibited during the descent phase of each task (ascent was similar). The effect size (ES) of each difference is also described by the inclusion of 1 (ES = 0.2–0.5) or 2 (0.5–0.8) asterisks. A positive change reflects less motion posttraining. The model animations highlight the pre-post changes observed for 1 participant from the *MOV* group. Data are presented for the low-load/low-velocity (LLLV), low-load/high-velocity (LLHV), high-load/low-velocity (HLLV), and high-load/high-velocity (HLHV) conditions.

Japan) while participants sat with their shoulder adducted, elbow flexed to 90°, and wrist in a neutral position. Three maximal effort trials were performed with each hand. (d) Countermovement jump height was evaluated with a Vertec Jump Measuring Device (Gill Athletics, Champaign, IL, USA). Three maximal effort trials were performed. (e) Push-ups were performed until volitional fatigue while maintaining a neutral spine. A 0.10-m thick pad was placed beneath the chest to provide a target depth. The test was terminated when the arms could no longer be extended or the required depth was not achieved. (f) Trunk flexor endurance was established with a front plank. The test was terminated when an extended hip position or neutral spine posture could no longer be maintained. (g) A side plank was used as a second measure of trunk muscle endurance. The test was terminated when a straight-body position could no longer be maintained. (h) Trunk extensor endurance was estimated using the Biering-Sorensen test. The test was terminated when the body could no longer be held in a position parallel to the floor. Approximately 2 minutes of rest was

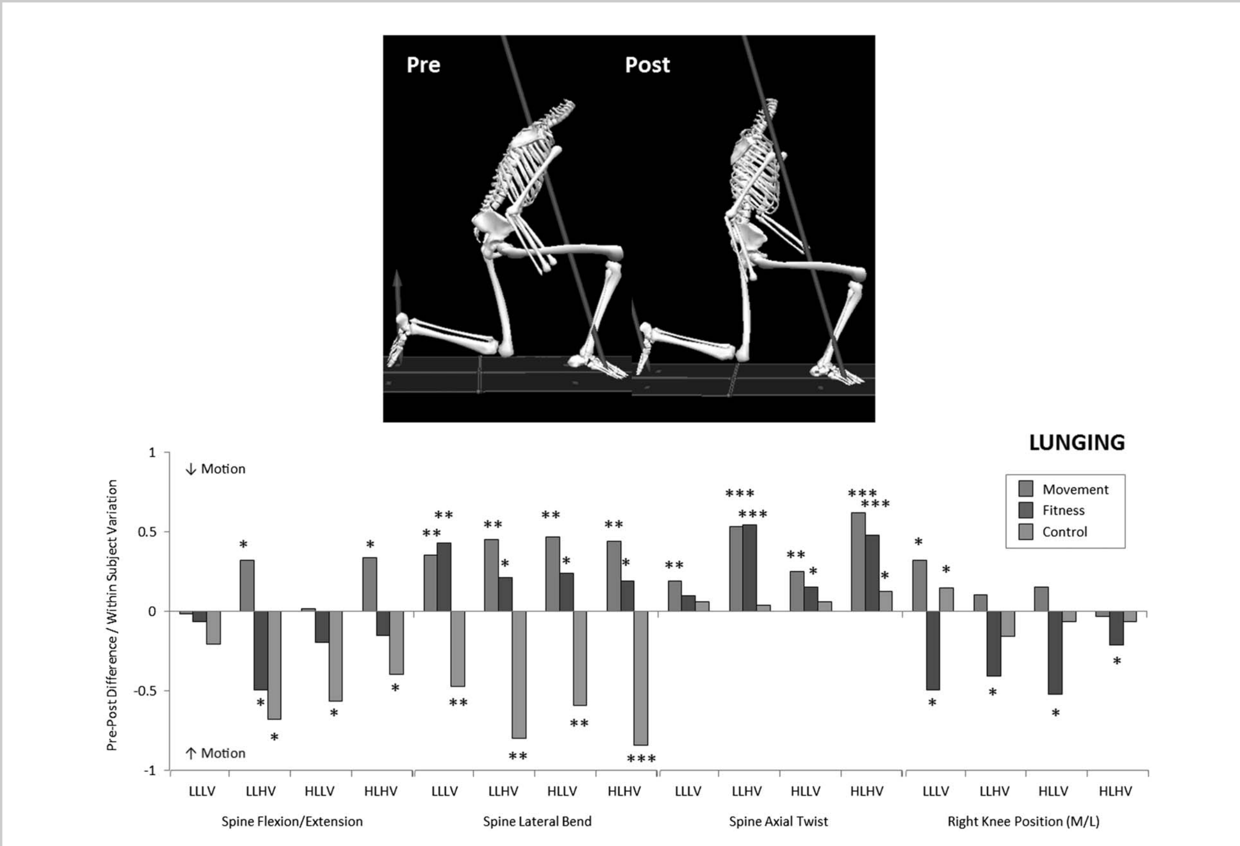

Figure 2. Lunge-specific adaptations in peak spine and knee motion for each condition (load × speed) and group. Changes are presented as a function of the maximum within-subject variation + 1*SD* and depict those exhibited during the descent phase (ascent was similar). The effect size (ES) of each difference is also described by the inclusion of 1 (ES = 0.2–0.5), 2 (0.5–0.8), or 3 (>0.8) asterisks. A positive change reflects less motion posttraining. The model animations highlight the pre-post changes observed for 1 participant from the *MOV* group. Data are presented for the low-load/low-velocity (LLLV), low-load/high-velocity (LLHV), high-load/low-velocity (HLLV), and high-load/high-velocity (HLHV) conditions.

given between each task. Participants' best performance on each test was used for comparative purposes.

Movement Testing. Participants were instrumented with reflective markers and familiarized with the 5 tasks using standardized instructions. The initial exposure to each task reflected a low external demand; the load and movement speed were low (LLLV–low load, low velocity). The lifts were performed with 6.8 kg, the squats and lunges were completed with body weight, and the push and pull loads (Keiser, Fresno, CA, USA) were set at 4 kg (15 units on Keiser display) and 6.5 kg (20 units), respectively. Three repetitions of each task were performed. The 5 tasks were randomized and approximately 15- and 60-second rest were given between each repetition and task, respectively. Once all tasks had been completed, the movement speed and external load were modified in 3 ways: (a) low load, high velocity (LLHV)–increase in movement speed only; participants were asked to complete each repetition as fast as was comfortable; (b) high load, low velocity–increase in external load only; the lifts were performed with 22.7 kg, the squats and lunges were performed with an 18.2-kg weighted vest, and the push and pull loads were set at 9.8 kg (30 units) and 13.6 kg (40 units), respectively; (c) high load, high velocity–increase in movement speed and external load. Each load/speed condition was performed sequentially based on the expected musculoskeletal demands. No feedback was given regarding task performance at any point throughout the investigation.

Training. After baseline testing, participants were assigned (stratified randomization) to one of the 3 groups, each matched for age, height, body mass, and composite FMS score: (a) movement-guided fitness training (MOV), (b) conventional fitness training (FIT), or (c) control (CON). The 2 interventions comprised 12-week, periodized exercise programs (MOV–4 phases, FIT–3 phases) designed to improve general fitness characteristics (e.g., aerobic capacity) and performance outcomes (e.g., treadmill time), but differed with regard to the selection of exercises, intensities, and

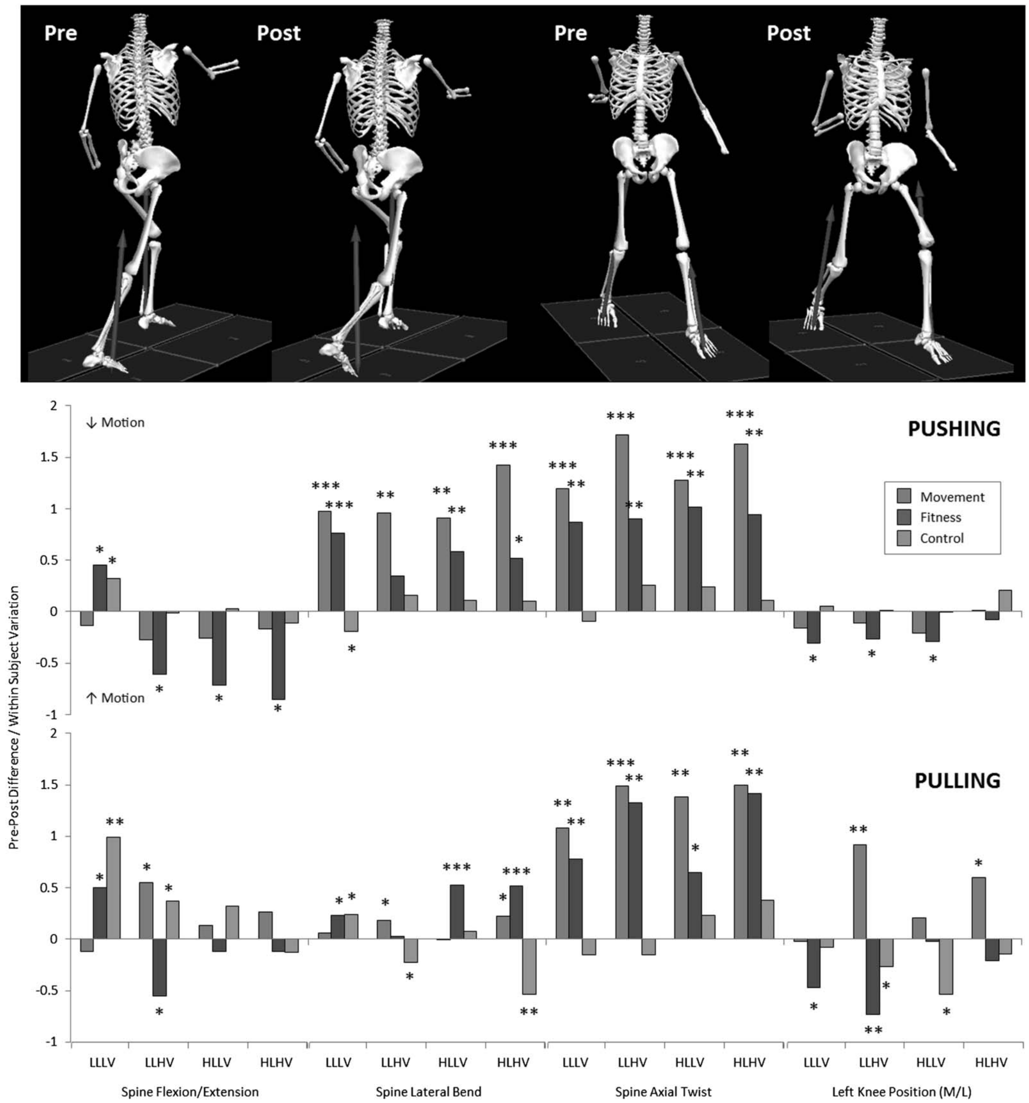

Figure 3. Push- and pull-specific adaptations in peak spine and knee motion for each condition (load × speed) and group. Changes are presented as a function of the maximum within-subject variation + 1*SD* and depict those exhibited during the first phase of each task (i.e., pushing away and pulling toward the body). The effect size (ES) of each difference is also described by the inclusion of 1 (ES = 0.2–0.5), 2 (0.5–0.8), or 3 (>0.8) asterisks. A positive change reflects less motion posttraining. The model animations highlight the pre-post changes observed for 1 participant from the *MOV* group. Data are presented for the low-load/low-velocity (LLLV), low-load/high-velocity (LLHV), high-load/low-velocity (HLLV), and high-load/high-velocity (HLHV) conditions.

training volumes (see Appendix), and the instruction and feedback provided by the coaches regarding *how* each exercise should be performed. This was done to contrast 2 dissimilar training methodologies, each intended to elicit different exercise adaptations, rather than to investigate the influence of any 1 specific factor such as volume, intensity, or coaching style. Throughout the 12 weeks, the MOV coach used instruction and feedback to reinforce "key" movement features that have been hypothesized or demonstrated to reduce injury risk (7,16,17,25). For example, the firefighters were made aware of the potential implications surrounding uncontrolled spine motion while executing all relevant exercises, and they were given cues to shape their movement behavior accordingly (see Appendix). When performing a front plank, front squat, or overhead press, the firefighters were taught how to achieve and maintain a "neutral" spine (i.e., the posture in which the spine's load-bearing capacity is near maximum). Effectively, the same "key" movement features, such as neutral spine and frontal plane knee alignment, were emphasized with every exercise such that the firefighters' movement patterns remained a primary focus as their muscular strength, power, flexibility, endurance, and cardiorespiratory efficiency were being enhanced in a progressive manner. Conversely, the primary objective of the FIT program was to make the firefighters as physically "fit" as possible. Exercise technique was monitored and feedback was provided when necessary for safety purposes, but the coach's emphasis was on maximizing performance and fitness outcomes in the gym environment. This mimicked the approaches of many popular high-intensity programs whereby the coach or trainer encourages the trainee to complete a specific number of repetitions or lift a particular load with little regard for the quality of their movement or the transfer of training.

Participants in both groups attended three 1.5-hour sessions each week at a local training facility and were coached by strength and conditioning professionals accredited by the NSCA. Trainees were asked to refrain from performing any additional exercise for the duration of the investigation. At no time were the specific objectives of the evaluations, the differences between each training group, or the study hypotheses discussed with the participants. The firefighters were asked to perform a battery of fitness tests and whole-body tasks in a laboratory setting before and after participating in a 12-week exercise program designed to improve their physical fitness. The coaches were also blinded to the laboratory-based testing protocols and instructed to refrain from sharing their thoughts regarding the test/study objectives with their group of firefighters. Participants were required to attend 30 of the 36 training sessions to be included in the analyses. Within 1 week of completing training (week 13), the firefighters returned for a second fitness and movement test. The CON participants were asked to maintain their current fitness regime for 12 weeks before returning to complete posttesting.

Data Collection and Signal Processing

During the laboratory session, three-dimensional motion data were measured using a passive motion capture system (Vicon, Centennial, CO, USA). Reflective markers were placed on 23 anatomical landmarks to assist in defining the end points of the trunk, pelvis, thighs, shanks, and feet to define an 8-segment rigid link model. The hip joint centers and knee joint axes were also determined "functionally" using similar methods to those described by Begon et al. (3) and Schwartz and Rozumalski (36). This method has been shown to improve the day-to-day reliability of the linked segment model (12). Sets of 5 markers, fixed to rigid pieces of plastic, were secured to the 8 body segments (i.e., trunk, pelvis, thighs, shanks, and feet) with Velcro straps and used to track their position and orientation in space. The pelvis cluster was secured to a custom belt worn throughout testing at the level of the sacrum, and the trunk cluster was fixed to a custom vest at the inferior border of the rib cage. One standing calibration trial was collected such that the orientation of each segment's local axis system could be determined through a transformation from an axis system embedded within each rigid body. The anatomical markers were removed once the calibration procedures were completed. The marker data were collected at 160 Hz and smoothed with a low-pass filter (fourth order dual-pass Butterworth) with an effective cut-off frequency of 6 Hz.

Data Analyses

Participants' movement patterns were characterized with 5 variables, each chosen to reflect a visually observable feature that has been previously cited as a possible mechanism for low back (7,25) or knee (16,17) injury. Visually observable characteristics were preferred given that the MOV coach based his instruction and feedback on these same characteristics. Spine flexion/extension (FLX), lateral bend (BND), and axial twist (TST) were computed by expressing the relative orientation of the rib cage with respect to the pelvis. The corresponding direction cosine matrix was decomposed with a Cardan rotation sequence of flexion/extension, lateral bend, and axial rotation to compute the spine angle about each axis. The orientation of the lumbar spine captured while standing in the anatomical position was defined as zero degrees. The positions of the left (LFT) and right knee (RGT) joint center in the medial/lateral direction were described relative to a body-fixed plane created using the corresponding hip joint, ankle joint, and distal foot (10).

To objectively define the start and end of each trial, event detection algorithms were created in Visual 3D by tracking the motion of the trunk, pelvis, right forearm (push and pull), and whole-body center of mass. To verify that events were defined as intended, model animations of all trials were inspected visually. Maximums and minimums of the 5 kinematic variables were computed. The "peak" of each variable was described as the deviation (maximum, minimum, or range) hypothesized to be most relevant to the types of injuries sustained by firefighters (i.e., FLX–flexion, BND and TST–range, LFT and RGT–medial displacement). For the purpose of this investigation, less motion posttraining was considered a positive adaptation indicative of improved control.

Statistical Analyses

The fitness-related adaptations to training were evaluated using a general linear model with 1 between- (group) and 1 within-subject (time) factor (Version 20.0; IBM SPSS Statistics, Armonk, NY, USA). Tukey post hoc comparisons were used to investigate the main effects and all significant interactions ($p \leq 0.05$).

Participants' movement-related adaptations were evaluated using the biological variability computed between and within the subjects. Two measurements were used to describe the magnitude of each pre-post change. An effect size (ES) was computed to describe the pre-post differences in FLX, BND, TST, LFT, and RGT relative to the pooled between-subject variation. An ES of one indicated that the pre-post difference was equal to the variation observed between participants. A positive effect implied that less motion was observed posttraining. A within-subject normalized difference (WND) was computed to express the pre-post differences relative to the maximum variation observed within participants (±1*SD* of the group mean). The maximum variability computed for any metric (i.e., max, min, or mean) or condition (e.g., LLLV) was used in this computation. The same approach was also used to examine the subject-specific responses for each dependent measure (11). A score greater than one or less than negative one indicated that the individual's posttraining change was greater than the average variability observed within participants (±1*SD*). A change of this magnitude is defined herein as a biologically significant change (11). Each load/movement speed condition was investigated separately. The strength of either variable was interpreted using the general guidelines offered by Cohen (8) for ES, whereby values of 0.2, 0.5, and 0.8 corresponded to small, moderate, and large changes, respectively.

Results

Fitness Adaptations

Posttraining, the movement group showed significant improvements ($p \leq 0.05$) on every measure of fitness with the exception of the left and right side plank (Table 2). Similarly, the fitness-trained participants improved ($p \leq 0.05$) every aspect of fitness with the exception of their flexibility, as was measured by the sit-and-reach (Table 2). The control group showed significant improvements on 2 of the 11 tests (left grip and max push-ups); however, in each case, the magnitude of change was smaller than that observed for either of the training groups.

Movement Adaptations

Lifting. The most substantial lifting adaptations were exhibited by the movement group (Figure 1). Less FLX was exhibited in each of the load/movement speed conditions (WND >0.5; ES >0.3 for 3 of 4 conditions). A similar trend was noted for LFT and RGT, although the only changes with an ES and WND greater than 0.2 were RGT during the low-load/high velocity and high load/low velocity conditions. The fitness-oriented intervention did not elicit any changes to the group's lifting pattern. In comparison, the control group exhibited 5 changes with a WND greater than 0.2, although each reflected a negative response with an increase in motion posttraining.

Squatting. The movement group showed marked improvements in LFT and RGT for each condition, although only RGT had a WND and ES greater than 0.3 (Figure 1). The largest posttraining changes (WND >0.6; ES >0.5) in RGT were seen during the high-load/high-velocity condition. A negative change in FLX was noted during the low-load/low-velocity condition (WND >0.4; ES >0.2); however, similar adaptations were not found with any other load/movement speed combination. Among the conventional fitness-training group, marked increases in FLX were observed across all conditions (WND >0.9; ES >0.4). A similar negative response was noted in LFT and RGT, although the magnitudes of change were much smaller and not consistent across all conditions. Control group participants did not exhibit any changes during their second testing session.

Lunging. The movement group exhibited improvements in FLX, BND, and TST across all conditions, albeit to varying degrees (Figure 2). The largest adaptations were observed for BND (WND >0.5; ES >0.5) and TST (WND >0.6; ES >0.8), and the posttraining changes in FLX and TST appeared to be speed dependent; greater adaptations were seen during the high-speed conditions. A positive change was noted in RGT during low load/low velocity (WND >0.3; ES >0.2). The fitness group also improved their ability to control BND and TST posttraining. However, unlike the movement group's participants, they performed the lunge with more FLX (WND >0.5; ES >0.2 during LLHV) and RGT (WND >0.3; ES >0.2 across conditions) posttraining. Notable changes in FLX and BND were also seen among the control group; however, in each case, they were negative.

Pushing. The movement group exhibited positive changes exceeding a WND of 1.4 and an ES of 0.8 in BND and TST (Figure 3). The movement-guided fitness intervention appeared to have little influence on FLX and LFT. The conventional fitness group exhibited similar posttraining changes in BND (WND >0.3; ES >0.2) and TST (WND >0.9; ES >0.5), although they also displayed negative changes in FLX (WND >0.6; ES >0.3) and LFT (WND >0.3; ES >0.3). The control group did not consistently exhibit significant changes in either direction.

Pulling. The most notable changes among the movement group were those seen in TST (WND >1.2; ES >0.6). The posttraining adaptations to FLX and BND were also positive, but the magnitude of change was not consistent across conditions (Figure 3). The movement-guided intervention appeared to have had a speed-dependent effect on LFT; the largest improvements were noted during low-load/high-velocity and high-load/high-velocity conditions (WND >0.6; ES >0.2). The conventional fitness intervention evoked similar improvements in TST, although the largest changes were seen when the pull was performed quickly (WND >1.3; ES >0.6). Positive changes in BND were seen during the 2 heavy conditions (WND >0.3; ES >0.4); however, as with the squat, lunge, and push, the fitness-oriented group also displayed more FLX and LFT posttraining. The control group did not consistently exhibit changes in either direction for any dependent measure.

Subject-Specific Adaptations

More movement group's participants exhibited significant changes (i.e., WND >1.0) in FLX, BND, TST, LFT, and RGT for each task, in comparison with the conventional fitness and control groups. Expressed as a percentage of the number of subjects in the group, averaged across variables, and tasks, 43% of all movement participants exhibited *only* positive biologically significant changes posttraining. This is in comparison with 30 and 23% for the fitness and control participants, respectively. The movement group also had the fewest number of participants exhibiting more spine and frontal plane knee motion posttraining. Expressed as percentage of the total number of participants, 19% of the movement group's participants showed *only* negative significant changes, in contrast to 26 and 36% from the fitness and control groups, respectively.

Discussion

The firefighters participating in both exercise interventions displayed significant changes in every aspect of physical fitness tested. However, only the MOV group members exhibited less spine and frontal plane knee motion while performing the 5 transfer tasks posttraining. Select FIT participants did show some improvement in these same measures, although the general tendency of those who completed the FIT program was to use movement strategies comprising more spine and frontal plane knee motion after the exercise intervention. This finding suggests that perhaps the physical preparation of firefighters, or any other high-risk occupational or athletic group, is likely unattainable by emphasizing improvements on general tests of physical fitness alone.

Being physically fit may play a role in the prevention of future injury (6,24), but alone it is likely insufficient for this purpose, given that the way in which movements are coordinated and controlled influences musculoskeletal loading. For example, poor torso extensor endurance has been cited as a marker for future low back trouble in men (4); yet, the sources of low-back pain may not be muscular in nature. Rather, superior trunk muscle endurance could provide the opportunity to control spinal alignment for extended periods of time by delaying fatigue-induced deficits in neuromuscular control (37). But, if an individual is unable (e.g., proprioception deficits unrelated to fatigue process) or does not (e.g., personal preference or learned behavior) control the motion of their spine for reasons other than lack of muscular endurance, the risk of developing low-back disorders may be unaffected by improving trunk muscle endurance. Indeed, members of the FIT group displayed superior trunk muscle endurance posttraining; yet, they also exhibited significantly greater spine flexion when executing squatting movements. Similarly, Hilyer et al. (18) found that improving flexibility in firefighters did not reduce their injury risk, perhaps because addressing joint range of motion in isolation will not necessarily lead to "functional" changes (27). Furthermore, "plyometric" and "core strengthening" programs, designed to improve various components of physical fitness without the provision of movement-oriented instruction/feedback, have been unable to consistently reduce the incidence of anterior cruciate ligament injury (33) and low-back pain (5,30), respectively. A firefighter's job is physically demanding, and they must be physically fit to meet the demands of their work without suffering adverse health outcomes (e.g., cardiac events). However, being physically fit is unlikely sufficient to reduce injury risk among these public protectors given that movement behaviors and musculoskeletal loading patterns are affected by a host of interacting individual, task, and environmental constraints (9).

To address the incidence of exercise-related injuries among firefighters (34) and establish a framework to further develop and implement in future work, the MOV coach focused his attention on the motions exhibited by trainees when they were exercising. Several critical observations ("key" kinematic features) that have been linked to reduced tissue loading and the prevention of musculoskeletal injury (e.g., control of frontal plane lower extremity alignment (16)) were (re)enforced through instruction and feedback during training. Without providing explicit instruction regarding the execution of each transfer task, improvements in spine and frontal plane knee motion control were noted posttraining in firefighters who received this type of coaching. This suggests that movement behavior and physical fitness adaptations can be elicited through a movement-oriented exercise approach. Using exercise to target the motion patterns that drive elevated joint loading has been hypothesized as one of the most effective training strategies to protect against future anterior cruciate ligament injury (29). However, to the authors' knowledge, this is the first study to use this type of training methodology to elicit movement-related changes across several unrehearsed tasks of varying demands.

To become more proficient with a particular motor skill, be it a job task or exercise, it is often suggested that you must repeatedly perform the specific skill (2). However, without the physical capacity (e.g., strength, endurance, etc.) or body awareness to perform safely and effectively, practicing a task does not guarantee that trainees will use low-risk movement strategies. Moreover, leaving "risky" movement behavior unchecked during training could eventually result in cumulative tissue damage. This may be one of the reasons why a large percentage of the training-related injuries sustained by firefighters (34) and soldiers (1) are categorized as being of the overuse variety. In an effort to become better physically prepared, they could be engraining movement behaviors that increase their risk of future injury. Because the FIT participants were not provided with explicit feedback regarding the critical aspects of their motions while performing each exercise, they may have spent 12 weeks reinforcing undesirable patterns of movement coordination and control. As a result, when tested posttraining, their performance might have reflected their practiced behaviors. In contrast, the MOV participants may have exhibited less spine and frontal plane knee motion posttraining because they were provided with explicit instruction and feedback pertaining to their movements throughout, although it is acknowledged that the influence of coaching cannot be isolated from the selection of exercises, training intensities, and volume of loading.

Results of this investigation lend support to the notion that exercise can be used to change movement behavior, provided that movement-oriented instruction and feedback is offered when exercising. However, it should be noted that no 2 participants responded in the same way across all tasks and conditions. More firefighters from the MOV intervention did exhibit positive changes posttraining in comparison with those from FIT, but the group adaptations did not reflect those of *all* participants. For example, every firefighter participating in FIT did not exhibit more spine flexion while squatting, as was seen in the group response. It must also be stated that each participant did not perform in the same manner before they began training. Certain firefighters exhibited little spine and frontal plane knee motion when first performing each of the transfer tasks and may therefore have shown minimal change, despite the fact that their movement patterns would be perceived by an observer as "good." Given the possibility that many participants had never considered *how* to coordinate and control their movements when exercising, it is also conceivable that the instructions and feedback caused some individuals to focus on a single aspect of their movement, thereby neglecting one or more of the other "key" features. This may also have been influenced by their (un)familiarity with the exercises performed, as the participating firefighters had a range of prior experiences. Because there are several plausible explanations for why the group's response was not indicative of each participant, in future work, it may be critical to examine each participant's adaptations if trying to interpret the transfer of training.

Practical Applications

This study shows that exercise could be an effective tool to reduce musculoskeletal injury risk, provided that generalizable movement-oriented instructions and feedback are used to reinforce "protective" behaviors (e.g., "maintain control of frontal plane knee motion when…"). Conversely, the data here suggest that emphasizing physical fitness alone may not reduce occupational injury potential, as these same protective movement patterns are unlikely to emerge without directed efforts to transfer these exercise adaptations. Despite showing significant improvements in fitness, the FIT participants were also found to change their movement behavior in ways that could increase the risk of sustaining a future exercise-, training-, or fireground-related injury. The degree to which exercise adaptations transfer is most likely individual-, task-, and program-specific. However, the finding that firefighters who received movement-oriented exercise instructions and feedback were less likely to use "risky" movement behaviors in unrehearsed tasks is promising.

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Appendix:

Table A1. The FIT training 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	DB 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	DB 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	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	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 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-ups	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 × 20	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 × 20	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 × 20	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	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)			

During the first 3 weeks of each phase, the FIT coach modified participants' training loads 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). Exercises labeled with the same number (e.g., 1A, 1B, and 1C) were performed in succession before completing a second set.

Table A2. The MOV training template.

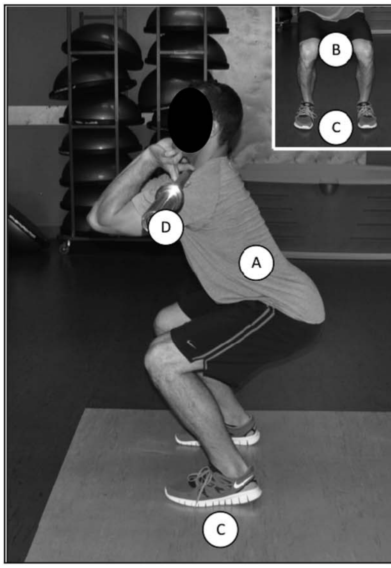
		Phase 1		Phase 2				Phase 3				Phase 4	
Day 1		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12
1A	Upper body push	3 × 8	3 × 8	3 × 12	3 × 12	3 × 12	3 × 12	4 × 15	4 × 15	4 × 15	4 × 15	3 × 8	3 × 8
1B	Supplemental	NA	NA	3 × 5	3 × 5	3 × 5	3 × 5	3 × 5	3 × 5	3 × 5	3 × 5	3 × 5	3 × 5
1C	Lower body pull	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	Supplemental	NA	NA	NA	NA	NA	NA	3 × 8	3 × 8	3 × 8	3 × 8	3 × 5	3 × 5
	Rest: 45 s between sets												
2A	Rotation	3 × 8	3 × 8	3 × 12	3 × 12	3 × 12	3 × 12	NA	NA	NA	NA	3 × 6	3 × 6
2B	Supplemental	2 × 6	2 × 6	2 × 5	2 × 5	2 × 5	2 × 5	NA	NA	NA	NA	2 × 5	2 × 5
	Rest: 45 s between sets												
3A	Upper body push	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	Lower body pull	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, 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)	

(continued on next page)

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	Lower body push	3 × 8	3 × 8	3 × 10	3 × 10	3 × 10	3 × 10	4 × 12	4 × 12	4 × 12	4 × 12	3 × 6	3 × 6
1B	Supplemental	NA	NA	3 × 5	3 × 5	3 × 5	3 × 5	3 × 6	3 × 6	3 × 6	3 × 6	3 × 5	3 × 5
1C	Upper body pull	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	Supplemental	NA	NA	NA	NA	NA	NA	3 × 6	3 × 6	3 × 6	3 × 6	3 × 5	3 × 5
	Rest: 45 s between sets												
2A	Rotation	3 × 8	3 × 8	3 × 10	3 × 10	3 × 10	3 × 10	NA	NA	NA	NA	2 × 6	2 × 6
2B	Supplemental	2 × 6	2 × 6	2 × 8	2 × 8	2 × 8	2 × 8	NA	NA	NA	NA	2 × 6	2 × 6
	Rest: 45 s between sets												
3A	Lower body push	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	Upper body pull	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, 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	Upper/lower push	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	Supplemental	NA	NA	3 × 5	3 × 5	3 × 5	3 × 5	3 × 6	3 × 6	3 × 6	3 × 6	3 × 5	3 × 5
1C	Upper/lower pull	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	Supplemental	NA	NA	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	Rotation	3 × 10	3 × 10	3 × 8	3 × 8	3 × 8	3 × 8	NA	NA	NA	NA	3 × 6	3 × 6
2B	Supplemental	2 × 6	2 × 6	2 × 5	2 × 5	2 × 5	2 × 5	NA	NA	NA	NA	2 × 8	2 × 8
	Rest: 45 s between sets												
3A	Lower body push	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	Upper body pull	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, 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)	

The MOV coach modified participants' training loads 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 participants' heart rates as measured during their baseline fitness test. Exercises labeled with the same number (e.g., 1A, 1B, and 1C) were performed in succession before completing a second set. Range of motion (ROM) activities included various low-intensity flexibility/mobility (e.g., hamstring stretch) exercises.

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	• Elevating the heels will shift the COP forwards and may increase the external knee flexion moment, toes elevated may increase the hip flexion moment • Opposite influence internally
D. Position of external load (if applicable)	• 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

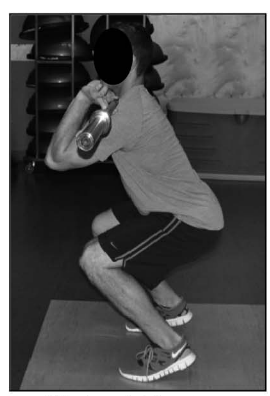
- Bodyweight squat
- Back squat
- Front squat
- Overhead squat
- Single leg squat
- Vertical jump

Common Observations to Address via Coaching

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

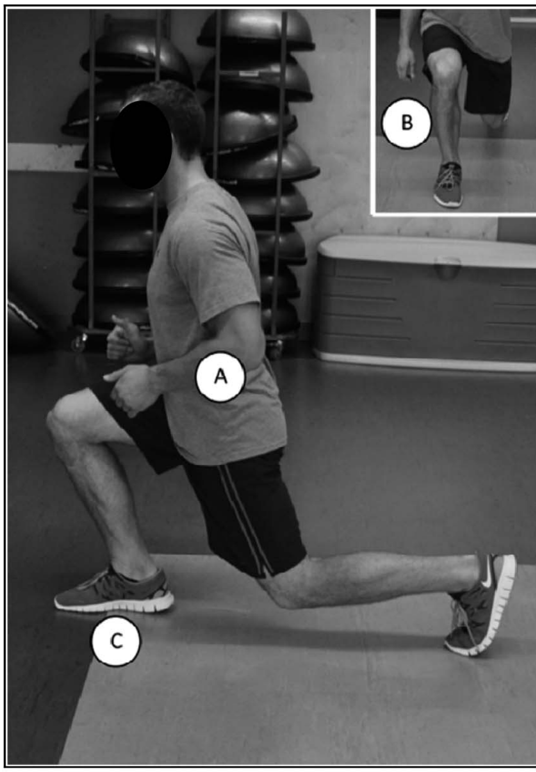
Coaching Cues

- 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	• Elevating the heel of the front foot (shift bodyweight forwards) may increase the external knee flexion moment, elevating the toes of the front foot (bodyweight backwards) may increase the hip flexion moment • Opposite influence internally

Lunge Pattern Exercises

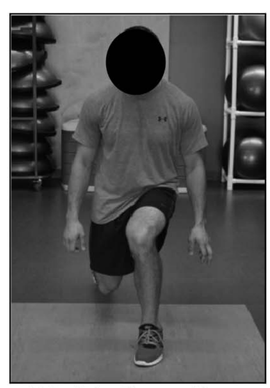
- Bodyweight lunge
- Split squat
- Back lunge
- Front lunge
- Running
- Bounding

Common Observations to Address via Coaching

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

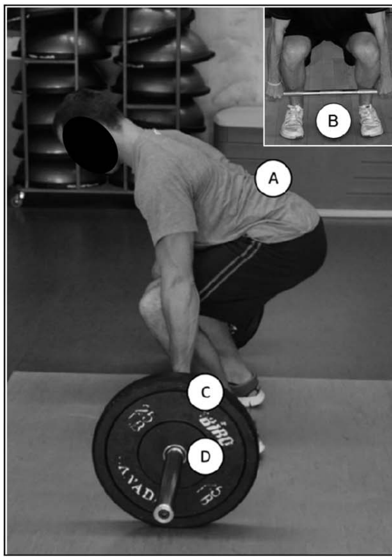
Coaching Cues

- 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

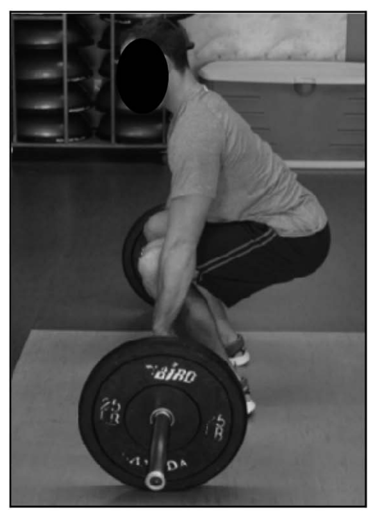
- Deadlift
- Romanian deadlift (RDL)
- Single leg RDL
- Cable lift
- Bent-over row
- RDL-to-row

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

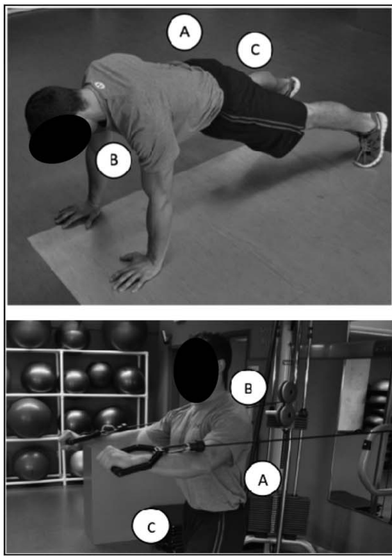
Coaching Cues

- 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

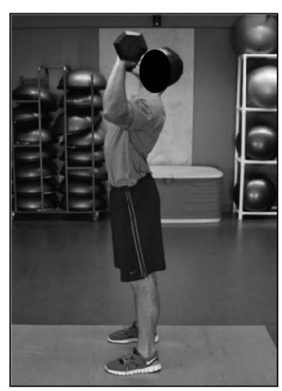
- Push-up
- Bench press
- Overhead press (military)
- Single arm push-up
- Single arm press
- Cable chop/press

Common Observations to Address via Coaching

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

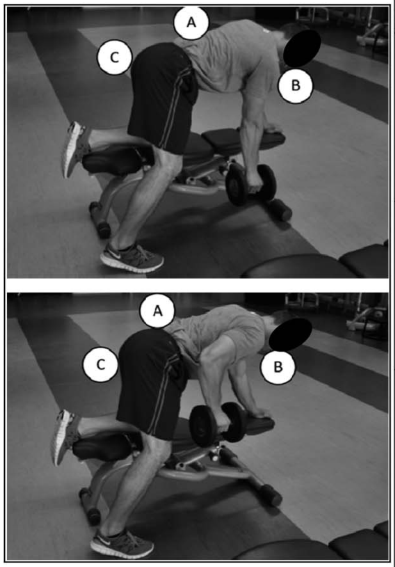
Coaching Cues

- 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



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. 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