The Time Course of Health, Fitness, and Occupational Performance Changes in Recruits across a Fire Academy

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ABSTRACT

WOHLGEMUTH, K. J., G. R. GERSTNER, H. K. GIULIANI-DEWIG, J. A. MOTA, A. E. SMITH-RYAN, and E. D. RYAN. The Time Course of Health, Fitness, and Occupational Performance Changes in Recruits across a Fire Academy. *Med. Sci. Sports Exerc.*, Vol. 55, No. 6, pp. 1087–1096, 2023. **Purpose:** The purpose of this study was to examine the time course of health, fitness, and occupational performance changes in firefighter recruits across a fire academy. **Methods:** Nineteen recruits (24.9 ± 4.3 yr; 26.7 ± 3.1 kg·m^{-2}) had their body composition, balance, vertical jump (VJ) performance, cardiorespiratory fitness (CRF), upper and lower body strength, hamstrings-to-quadriceps (H/Q) ratio, lower back endurance, and weighted stair climb (SC) performance assessed at the beginning (week 1 [W1]), midpoint (week 15 [W15]), and end (week 30 [W30]) of a fire academy. **Results:** The fire academy improved body composition, balance, CRF, leg extension strength, and SC performance from W1 to W15 ($P \leq 0.042$) which then plateaued at W30 ($P \geq 0.314$). Leg flexion strength and the H/Q ratio decreased from W1 to W15 ($P \leq 0.035$) and plateaued at W30 ($P \geq 0.947$). Upper body strength was similar at W1 and W15 ($P \geq 0.999$), but decreased at W30 ($P \leq 0.033$). However, no significant changes occurred across the academy for VJ performance or lower back endurance ($P \geq 0.090$). **Conclusions:** These findings highlight the positive effect of the academy on body composition, CRF, balance, SC performance, and leg extension strength. However, the decreases in upper body and leg flexion strength, the H/Q ratio, and lack of changes in VJ performance and low back endurance may highlight key areas of need to maximize injury prevention and performance enhancement efforts in the academy. Further, the varied time course of changes may help fire departments identify opportunities to modify exercise programming across their academies. **Key Words:** FIREFIGHTER, STAIR CLIMB, MUSCLE STRENGTH, AEROBIC CAPACITY, BODY COMPOSITION

Firefighters provide critical emergency services to communities across the country. There are over 1 million firefighters in the United States, with departments comprised of all or mostly career firefighters protecting the majority (69%) of the US population (1). Because of the strenuous and dangerous nature of their job and shift work, firefighters experience one of the highest rates of occupational injuries (2), with approximately one injury occurring every 8 min (3). Interestingly, previous work has shown that firefighters have the highest cardiovascular disease-related fatality rates of any public service occupational group (4). In addition, the most frequent on-duty nonfatal injuries include sprains and strains to the lower extremities and low back (2,5). Per year, the estimated cost of firefighter injuries is between $1.9 and $5.6 billion (6).

Although much of the time in the fire service is spent completing low-intensity activities, firefighters are required to perform a variety of strenuous critical and essential tasks including climbing stairs, ladder extension, hose dragging, equipment carry, forcible entry, search and rescue, and ceiling breaching (7). For example, during simulated tasks, firefighters have demonstrated high cardiometabolic responses including near maximal heart rates, and elevated oxygen consumption, plasma cortisol levels, and core temperature (8–10). In addition, various fitness variables have been shown to be key predictors of firefighter performance (11–13). For instance, faster weighted stair climb (SC) times are associated with greater lower extremity strength and power (11), while the majority of variance (82%) in Candidate

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Physical Ability Test performance can be explained by cardiorespiratory fitness (CRF) and anaerobic fatigue resistance (12). To prepare firefighters for the rigors of the job and the specific occupation-related demands of the fire service, firefighter recruits participate in a training academy. Training academies follow similar certification standards set by the National Fire Protection Association that are often obtained through a state fire academy, community college, or department depending on the state.

Few studies (14–16) have specifically examined the impact of the fire training academy on overall health and fitness; however, recent articles (14,15) have noted the fire academy improves recruit body composition, CRF, muscle strength, and muscular endurance. Interestingly, these studies (14,15) have focused on examining changes from enrollment to the end of the training academy. Other authors (17) have specifically examined training adaptations at multiple timepoints across the academy, which demonstrated estimated CRF and heart rate recovery plateaued at the midpoint of the 16-wk academy. Further, previous work in law enforcement academies have noted the time course of changes is different among various fitness (e.g., upper and lower body strength, power, CRF, muscular endurance) variables (18,19). These studies may highlight the need for future work to examine the time course of changes of health and fitness at multiple timepoints across the fire academy.

Additional work examining the impact of the training academy on the most common musculoskeletal firefighter injuries (e.g., lower extremity and low back) and simulated occupational performance may extend the work of these previous studies (14,15) and help to inform fire academy physical training recommendations that directly impact injury prevention and performance enhancement efforts. For example, the quadriceps-to-hamstring ratio and low back endurance assessments are important predictors of hamstring and/or knee injury (20–22) and low back dysfunction (23), respectively, whereas the weighted SC is considered one of the most challenging firefighter tasks (24). Thus, the purpose of the present study is to examine the impact of the fire training academy on the time course of changes in body composition, balance, vertical jump (VJ) performance, CRF, upper body (UB) and lower body strength, hamstrings-to-quadriceps ratio (H/Q), lower back endurance, and a weighted and timed SC task. Changes in these variables are impactful, as they have been shown to be the primary risk factors for the most common fatal and nonfatal firefighter injuries (4,16,23,25), predictors of firefighter performance (12,13,26–28), and performance of a critical and essential firefighter task (11).

METHODS

Participants

Nineteen (1 female) career firefighter recruits (mean ± SD; age 24.9 ± 4.3 yr; stature 175.9 ± 7.6 cm; BMI 26.7 ± 3.1 kg·m^{-2}) were recruited from a fire training academy at a department in northeast central region of North Carolina. All participants read and signed an informed consent document explaining the risks and benefits of participating in the study. Participants were also asked to complete a health history before participating in the study. Participants were medically cleared (by a physician) for participation in the training academy before laboratory testing. This study was approved by the university institutional review board.

Firefighter Recruit Training Academy

All 19 participants were enrolled in the same firefighter training academy for approximately 32 wk from April 29, 2019, to graduation on December 5, 2019. The first week of the academy consisted of orientation to the academy (i.e., introductions, human resources, paperwork, fire department history, fitness testing), followed by 10 wk of emergency medical technician training. The subsequent 21 wk of the academy focused on occupation-specific training (e.g., safety, forcible entry, ladders, ventilation). Recruits completed training for 8 h·d^{-1}, 5 d·wk^{-1} with approximately 7 h·d^{-1} designated for academy instruction.

Physical training weeks 1–11. The last hour of each instructional day was designated for physical training on Monday, Wednesday, and Friday. In the event of extreme heat, physical training would be the first hour of the day. On Tuesday and Thursday, the recruits would use that hour for detail cleanup of the training grounds. During the emergency medical technician portion of the academy (weeks 2–11), physical training focused on muscular strength and endurance (Monday and Friday) and CRF (Wednesday), where 20 to 30 min of each session included vigorous exercise. All sessions included an instructor or recruit led warm up (~10 min) and cool down (~10 min). All muscle strength and endurance sessions were structured in a "circuit style," which included body weight exercises due to minimal on-site equipment, but sometimes incorporated free weights, jump ropes, medicine balls, and tires. Training had a heavy focus on body weight squats, equipment carries (e.g., hose), pushups, and core exercises (e.g., planks). Cardiorespiratory fitness days typically included a cadence run (e.g., 120 steps per minute), a distance run (≤7 miles) or occasionally an interval run (i.e., repeated sprints).

Physical training weeks 12–32. During the fire-specific portion of the academy (weeks 12–32), approximately 20% of instruction was in the classroom and 80% was in the field. Recruits completed most of the field work in turnout gear and the majority of tasks included equipment carrying (i.e., ladder, hose, tools, rescue dummy). Dependent on weather conditions and the difficulty of the field training, structured physical training was implemented occasionally to accommodate adequate recovery. For instance, physical training would include low impact (e.g., no jumping) and moderate-intensity exercise that focused more on the portions of the body that were not targeted on that training day (e.g., if lower body was fatigued from climbing flights of stairs, the workout would focus on UB exercises).

Experimental Design

The participants completed three separate days of testing at the laboratory around the same time of day (±2 h). Participants arrived following an 8-h fast and were asked to refrain from exercise for 24 h, and vigorous exercise for 48 h outside of the fire academy. Also, participants refrained from consuming alcohol or caffeine 8 h before visiting the laboratory. The testing visits were scheduled around their academy training and occurred at the beginning (May 3, 2019; week 1 [W1]), midpoint (August 6, 2019; week 15 [W15]) and end (November 21, 2019; week 30 [W30]) of the academy. Upon arrival to the laboratory, participants read and signed an informed consent document, completed a health history questionnaire, had their body composition, balance, VJ, CRF, UB isometric muscle strength, lower body isometric muscle strength, lower back endurance, and a weighted and timed SC task assessed. Recruits were given a standardized breakfast shake (Carnation Breakfast Essentials Nutritional Drink: High Protein, Rich Milk Chocolate or Classic French Vanilla, 8 Fl Oz bottle) to consume following the VJ assessments to provide an additional rest time (~ 5min) before the CRF assessment during their laboratory visit. The order of testing was chosen to minimize the effect of each test on the subsequent assessments. All resting, lower intensity assessments, and those requiring heart rate to estimate CRF were performed before those that were more demanding.

Body Composition

Body mass (BM) and height were measured using a calibrated clinical scale (seca 769, Hamburg, Germany). Body composition was assessed using dual energy x-ray absorptiometry (DXA) (Lunar iDXA; GE Healthcare, Chicago, IL) to determine fat mass (FM), fat-free mass (FFM), and percent body fat (%BF). Participants were asked to wear loose athletic clothing and were free of metals and jewelry and were positioned in the supine position, centered on the DXA bed according to the manufacturer's guidelines.

Modified Star Excursion Balance Test

Balance was assessed using the modified star excursion balance test, which has been shown to be a reliable and valid predictor of lower extremity injury risk and used previously in firefighters (29–31). Before the test, the research team secured tape measures in the anterior, posteromedial, and posterolateral directions (i.e., straight ahead, backward toward the opposite leg, and backward away from the body, respectively) on the floor. The posteromedial and posterolateral tape measures were 135° from the anterior line. Participants stood with one foot at the center of the three lines and reached as far as possible with their non–weight-bearing foot in the three directions. The participant touched the tape measure with their toe and the distance was recorded. Once the toe touched the tape, the participant returned to the center tape mark and placed both feet on the floor (32). Before testing, participants watched a demonstration of the correct movements and then completed three familiarization trials in each direction for both legs to minimize a learning effect (31). Participants kept the weight bearing foot firmly on the ground with their hands on their hips for the duration of each trial. Moving the weight bearing foot, losing balance, or removing the hands from the hips caused the participant to restart the trial. Three trials per leg were performed in all directions and the participant switched legs between each trial. The maximal reach distance in centimeters (cm) was recorded for each limb in all directions. For parsimony, the maximal reach distance of the dominant limb was normalized to leg length (distance in cm from anterior superior iliac spine to the distal medial malleolus). Further, a composite score from all three directions was created for the dominant limb. All trials were completed in athletic shoes on a nonslip surface.

Countermovement Jump

Participants were asked to perform a no-step maximal countermovement VJ as described previously (33). A Tendo Weightlifting Analyzer (Tendo Sports Machines, Trencin, Slovak Republic) and a jump mat (Just Jump or Run; Probotics, Inc., Huntsville, AL) were used to measure average power (W) and jump height (cm), respectively. Participants were positioned with their feet shoulder width apart and their hands on their hips standing on the jump mat. A rapid descending squat movement was allowed before the rapid ascending jump. Participants were asked to jump with both feet at the same time and land in the same position. The Tendo Weightlifting Analyzer was used according to manufacturer's guidelines with the unit cord attached to a belt behind the participant slightly below the participant's umbilicus. The Tendo unit was placed on the floor behind them and allowed the cord to extend without impeding jumping technique. The jump mat measured jump height based on flight time, which was the time between when the participant's feet left the mat and when their feet landed. The jump was repeated if both feet did not land at the same time or the same position. Following three submaximal attempts, three maximal jumps were completed, each separated by 30 s of rest. The jump with the highest jump height from all three jumps was used for analysis.

Cardiorespiratory Fitness

Maximal oxygen consumption ($\dot{V}O_{2max}$) was estimated using a single-stage, treadmill (4FRONT; Woodway, Woodway USA, Inc., Waukesha, WI) based submaximal cardiorespiratory assessment (34). Participants performed a 4-min warm-up before beginning the $\dot{V}O_{2max}$ assessment. Heart rate (HR) was monitored during the warm-up, $\dot{V}O_{2max}$ assessment, and cool down period using a Polar chest strap heart rate monitor and watch (Polar Electro, Lake Success, NY) (34). The warm-up consisted of walking on the treadmill at a self-chosen speed between 3.22 and 7.24 km·h^{-1} (2.0 to 4.5 mph, respectively) at a 0% grade to elicit a HR within 50 to 70% of their age predicted HR maximum (HR max = 207 – 0.7 × age) (35). Following completion of the warm-up protocol, participants continued to walk at the same speed for 4 min at a 5% grade. Heart rate was recorded during the last 15 s of the last 2 min of the test (minutes 3 and 4) and averaged to determine the final, average HR (34–36). A cool-down was completed at a 0% grade as the last stage of the CRF assessment. To estimate $\dot{V}O_{2max}$, the following equation was used (34):

$$\dot{V}O_{2max} = 15.1 + 21.8 \times \text{speed (mph)} - 0.327 \times \text{HR (bpm)} - 0.263 \times \text{speed} \times \text{age (year)} + 0.00504 \times \text{HR} \times \text{age} + 5.98 \times \text{gender (0 female, 1 male)}$$

Upper Body Strength

A custom-built, portable isometric dynamometer was used to assess UB strength as described previously (37). Participants stood on aluminum plate and held a metal bar that was attached to the plate with a chain and an in-series tensiometer. The participants grasped the bar with a pronated grip, with arms and legs shoulder width apart. The chain length was adjusted to ensure the handle was two centimeters below the umbilicus of each participant before performing the upright row. This was recorded so that the same setup was used for each testing session. After completing a warm-up (50%–75% of their perceived max), participants completed three maximal voluntary contractions (MVC) with 90 s of rest between each MVC. Instructions were to pull "as hard and as fast as possible" for 3 to 5 s. Participants were provided clear instructions to not perform a countermovement while maintaining an upright posture. Strong verbal encouragement was given throughout each MVC.

Lower Body Strength

Isometric peak torque (PT) of the dominant leg extensors and flexors was assessed using a calibrated dynamometer (HUMAC Norm; Computer Sports Medicine Inc., Stoughton, M) as described previously (37). Leg dominance was determined as the preferred foot to kick a soccer ball. Participants were seated in the dynamometer with the dominant knee flexed at 60° (full extension = 0°). Note, one recruit asked to test his nondominant leg due to a previous injury. The lower leg was secured to the lever arm of the dynamometer using a Velcro strap placed five centimeters proximal from the lateral malleolus of the participant's ankle. The dynamometer's axis of rotation was aligned with the center of the participant's dominant knee. Seatbelts were fastened across the participant's waist, contralateral limb, and chest to secure the torso. Arms were also crossed over the chest during the MVC. Before performing the MVC, a warm-up of three submaximal muscle actions (between 50% and 75% of perceived max), were performed. Participants were told to kick out (extension) or pull back (flexion) "as hard and as fast as possible." Each MVC was held for 3 to 4 s and strong verbal encouragement was given throughout each MVC. Participants completed two to three leg extension and flexion MVC separated with 90 s of rest. The order of MVC was randomized before data collection. In addition, the H/Q ratio was also determined by dividing leg flexion (LF) MVC PT by leg extension (LE) MVC PT (20).

Signal Processing

Torque (N·m) and force (N) were sampled at 2 kHz using a Biopac data acquisition system (MP150WSW; Biopac Systems, Inc., Goleta, CA), accompanying Acknowledge software (Biopac System Inc., Goleta, CA), and stored on a personal computer (ThinkPad T420; Lenovo, Morrisville, NC). A custom-written software program (LabVIEW 15; National Instruments, Austin, TX) was used to process torque signals offline. All signals were corrected for baseline passive tension and filtered using a fourth order, zero phase shift low pass Butterworth filter with a 150-Hz cutoff frequency (38). Isometric PT was determined as the highest 500-ms epoch for both LF and LE PT, and UB peak force (PF).

Lower Back Endurance

Low back endurance was determined using a Modified Biering-Sorenson Test. Each participant was positioned prone in a horizontal Roman chair with the anterior superior iliac spines resting on the superior edge of the pelvic pad. Their hands were crossed in front of their chest and their ankles were secured under the ankle pad with their legs straight. Participants were asked to bring their torso to parallel and maintain a horizontal position for as long as possible. The investigator started the timer as soon as the torso was horizontal and stopped the timer when the participant could no longer maintain the starting position. If the torso dropped below 10° of the horizontal position, one warning was given to regain horizontal position.

Stair Climb Performance

To assess occupational performance, all participants performed a timed and weighted SC assessment as described previously (11). Before the SC, participants performed a warm-up by ascending 26 stairs once in athletic clothes and shoes (39). Participants were then outfitted with a 22.73-kg weight vest (Z Fitness Inc., Sane Jose, CA) positioned over the shoulders and on the chest to simulate the weight of their personal protective equipment and self-contained breathing apparatus. The vest was secured against the body with Velcro straps to limit movement during the assessment and adjusted to fit comfortably. A verbal command signaled the start of the assessment and the start of timing. Beginning at the bottom of the stairs, the participants ascended and descended the stairs four times (stair height = 18.5 cm) for a total 104 steps. Participants were asked to not use the handrails, unless they lost their balance during the assessment and each step was touched with one foot as quickly as possible. The stopwatch was stopped when both of the participant's feet touched the bottom of the stairs.

Statistical Analyses

A mixed model approach and compound symmetry covariance structure was used to examine separate one-way repeated measures analysis of variance (ANOVA) to determine potential changes in body composition (DXA %BF, DXA FM, DXA FFM, BM), balance, VJ performance (average power, jump height), CRF, upper and lower body maximal strength, H/Q ratio, lower back endurance, and the timed SC task throughout the training academy. This model was chosen to incorporate all available data points at each measurement timepoint. Contrasts were corrected with Bonferroni *post hoc* pairwise comparisons. Model estimated means ± standard error (SE) along with 95% confidence intervals were produced. An alpha level of ≤0.05 was set *a priori* to determine statistical significance. Measures were analyzed using SAS software, version 9.4 (SAS Institute Inc., Cary, NC).

RESULTS

The mean ± SE and 95% confidence intervals for all variables at each timepoint are presented in Table 1. Nineteen recruits completed the W1 and W15 testing visits (n = 19); however, one recruit did not complete the W30 testing session (n = 18).

Body Composition

There were significant main effects for time for evaluating DXA FM, FFM, and %BF ($P \leq 0.020$); however, there was no main effect for BM ($P = 0.634$). The recruits FM and %BF were significantly lower at W30 of the academy when compared with W1 ($P \leq 0.026$), with no significant difference between W15 and W30 of the academy ($P \geq 0.999$). However, %BF was significantly lower at W15 when compared with W1 ($P = 0.020$) of the academy, whereas no significant ($P = 0.086$) change in FM was noted between W1 and W15 of the academy (Fig. 1). In addition, FFM was greater at W15 and W30 when compared with W1 of the academy ($P < 0.001$); however, there were no significant differences between W15 and W30 of the academy ($P = 0.999$).

Modified Star Excursion Balance Test

There was a significant main effect for time for the posteromedial reach, posterolateral reach, and composite score ($P \leq 0.006$); however, there was no main effect for the anterior reach ($P = 0.297$). The posteromedial reach, posterolateral reach, and composite score increased from W1 to W15 of the academy ($P \leq 0.033$) as well as from W1 to W30 of the academy ($P \leq 0.015$); however, there was no significant difference between W15 and the W1 and W30 testing points ($P \geq 0.999$) (Fig. 1).

Countermovement Jump

There was no main effect for time for average power and jump height ($P \geq 0.090$).

Cardiorespiratory Fitness

There was a significant main effect for time for estimated $\dot{V}O_{2max}$ ($P < 0.001$). Estimated $\dot{V}O_{2max}$ significantly increased from W1 to the W15 and W30 testing points ($P < 0.001$); however, there was no significant difference between W15 and W30 of the academy ($P = 0.314$) (Fig. 1).

Upper Body Strength

There was a significant main effect for time for UB PF ($P = 0.003$). Upper body PF was significantly less at W30 of the academy than W1 and W15 of the academy ($P \leq 0.033$); however, there was no significant difference between W1 and W15 of the academy ($P \geq 0.999$) (Fig. 1).

Lower Body Strength

There was a significant main effect for time for LE PT, LF PT, and the H/Q ratio ($P \leq 0.008$) (Fig. 1). Leg extension PT

TABLE 1. Model estimated means ± SE and 95% confidence intervals for the beginning, mid, and end of academy outcome variables.

	Beginning		Mid		End[a]	
Outcomes	Mean ± SE	95% CI	Mean ± SE	95% CI	Mean ± SE	95% CI
BM (kg)	82.82 ± 3.02	76.69–88.95	82.54 ± 3.02	76.41–88.66	83.11 ± 3.02	76.97–89.24
FM (kg)	17.23 ± 1.34	14.51–19.95	16.18 ± 1.34	13.46–18.90	15.93 ± 1.34*	13.20–18.66
FFM (kg)	62.26 ± 2.19	57.81–66.71	63.55 ± 2.19**	59.10–68.00	63.62 ± 2.19*	59.17–68.07
%BF	20.55 ± 1.24	18.04–23.07	19.25 ± 1.24**	16.74–21.77	18.93 ± 1.24*	16.41–21.45
Normalized composite score	2.43 ± 0.06	2.31–2.56	2.56 ± 0.06**	2.43–2.69	2.59 ± 0.06*	2.46–2.72
Normalized anterior reach	0.60 ± 0.02	0.55–0.64	0.60 ± 0.02	0.55–0.64	0.63 ± 0.02	0.58–0.67
Normalized posteromedial reach	0.90 ± 0.03	0.84–0.95	0.96 ± 0.03**	0.90–1.01	0.96 ± 0.03*	0.90–1.01
Normalized posterolateral reach	0.94 ± 0.02	0.89–0.99	1.00 ± 0.02**	0.96–1.05	1.01 ± 0.02*	0.96–1.05
Average power (W)	1171.84 ± 46.93	1076.57–1267.11	1177.42 ± 46.93	1082.15–1272.69	1206.54 ± 47.23	1110.66–1302.43
Jump height (cm)	50.83 ± 1.94	46.90–54.76	50.06 ± 1.94	46.13–54.00	51.82 ± 1.94	47.87–55.76
Estimated $\dot{V}O_{2max}$ (mL·kg^{-1}·min^{-1})	52.56 ± 1.18	50.16–54.96	56.42 ± 1.18**	54.02–58.82	55.62 ± 1.19*	53.21–58.02
UB PF (N)	826.04 ± 24.42	776.47–875.62	815.63 ± 24.42	766.06–865.21	783.69 ± 24.53*,***	733.88–833.50
LE PT (Nm)	226.58 ± 12.29	201.62–251.55	249.48 ± 12.29**	224.51–274.45	256.61 ± 12.42*	231.39–281.83
LF PT (Nm)	135.23 ± 7.70	119.60–150.86	121.76 ± 7.70**	106.12–137.39	119.24 ± 7.77*	103.47–135.01
H/Q ratio	0.60 ± 0.02	0.56–0.65	0.49 ± 0.02**	0.45–0.53	0.46 ± 0.02*	0.42–0.51
Lower back endurance (s)	129.32 ± 10.53	107.94–150.69	121.21 ± 10.53	99.84–142.58	129.68 ± 10.62	108.12–151.25
SC (s)	69.85 ± 1.70	66.39–73.31	65.36 ± 1.70**	61.90–68.82	63.81 ± 1.72*	60.32–67.29

[a]N = 18.
*P < 0.05, significant difference between the beginning and end of the academy.
**P < 0.05, significant difference between the beginning and midpoint of the academy.
***P < 0.05, significant difference between the midpoint and end of the academy.
95% CI, 95% confidence interval.

APPLIED SCIENCES

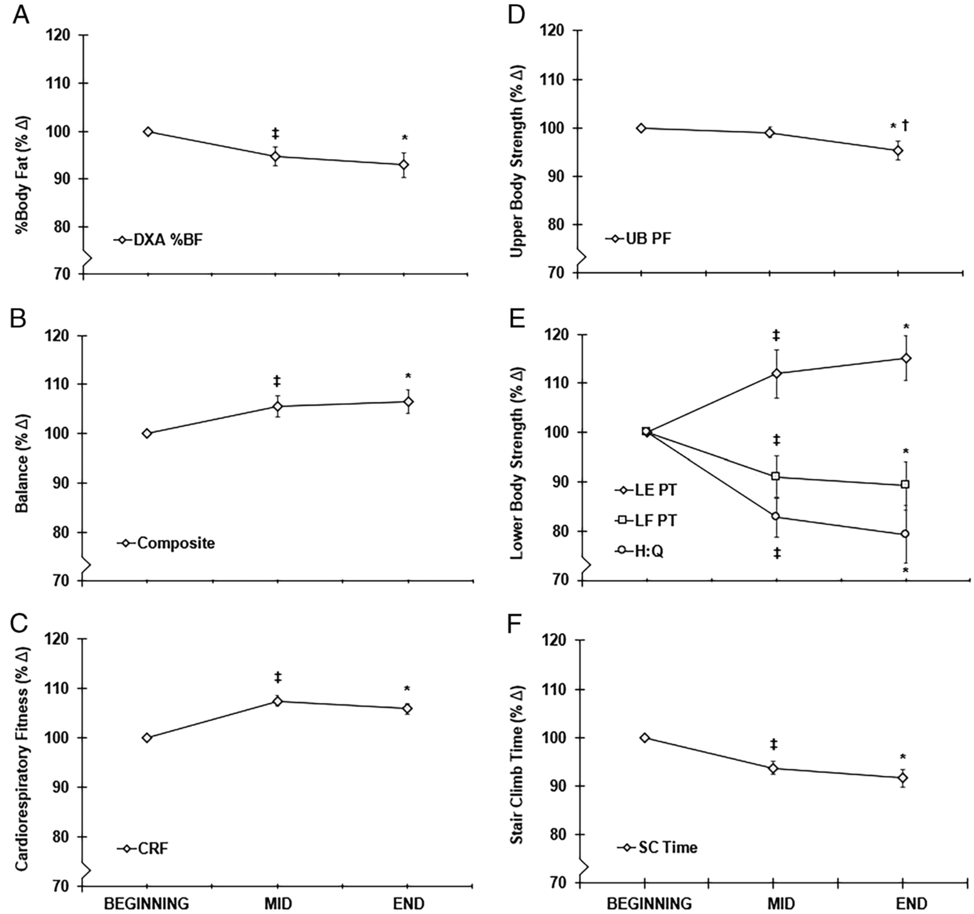

FIGURE 1—Raw percent changes (from beginning of the academy) for (A) body fat percentage (DXA %BF), (B) balance (composite), (C) CRF, (D) UB PF, (E) lower body strength (LE PT, LF PT, H/Q), and (F) SC time over the course of the academy. Note: *N* = 19 beginning to midpoint percent changes; *N* = 18 beginning to end percent changes. ‡*P* < 0.05, significant difference between the beginning and midpoint of the academy †*P* < 0.05, significant difference between the midpoint and end of the academy **P* < 0.05, significant difference between the beginning and end of the academy.

significantly increased at both W15 and W30 when compared with W1 of the academy ($P \leq 0.042$); however, there was no significant difference between W15 and W30 ($P = 0.999$). Leg flexion PT significantly decreased at both W15 and W30 when compared with W1 of the academy ($P \leq 0.035$); however, there was no significant difference between W15 and W30 of the academy ($P = 0.999$). Further, the H/Q ratio was significantly lower at both W15 and W30 when compared with W1 of the academy ($P < 0.001$); however, there was no significant difference between W15 and W30 of the academy ($P = 0.947$).

Lower Back Endurance

There was no main effect for time for lower back endurance ($P = 0.416$).

Stair Climb Performance

There was a significant main effect for time for SC performance ($P < 0.001$). Stair climb performance was faster at both W15 and W30 ($P \leq 0.001$) when compared with W1 of the academy; however, there was no significant difference between W15 and W30 of the academy ($P = 0.479$) (Fig. 1).

DISCUSSION

The present study comprehensively examined health and fitness variables in recruits previously identified as risk factors (15,23,26,29,40,41) for the primary fatal and nonfatal injuries in the fire service, in addition to predictors of simulated firefighter performance (11,39,40) across the fire academy. The primary findings indicated that body composition, balance, CRF, LE strength, and SC performance improved across the training academy; however, UB PF, LF strength, and the H/Q ratio decreased across the academy. Lastly, VJ performance (i.e., power and height) and lower back endurance remained unchanged across the academy.

Body Composition

The results of the current study indicated no significant changes in BM across the entire 32-wk training academy. However, other body composition variables (i.e., FFM, %BF) improved from W1 to W15 but plateaued from W15 to W30 of the academy. Similarly, there was a small, nonsignificant reduction in FM from W1 to W15 of the academy, but a significant decrease across the entirety of the academy and a plateau from W15 to W30 of the academy. Previous studies have published similar findings for changes in FFM and %BF, but differences in changes in BM across the full academy (14,15). For example, Cornell et al. (15) reported a 30.8% decrease in %BF and 4% increase in estimated FFM across the academy, while Lan et al. (14) reported a decline (2.8%) in %BF from baseline to graduation. In contrast to the current study findings, Cornell et al. (15) reported a decrease (3%) in BM across their academy. Further, it is important to note that academy duration for the current study (32 wk) was approximately twice as long as these previous studies ranging from 14 to 16 wk (14,15). When examining body composition changes at similar timepoints between studies (e.g., W1 to W15 for current study), the current study demonstrated significant improvements in FFM and %BF, which is in agreement with previous studies (14,15). Because of the similar initial body composition variables across studies for baseline BMI and %BF values (current study: BMI = 26.7 $kg \cdot m^{-2}$, %BF = 20.6; Cornell et al. (15): BMI = 26.9 $kg \cdot m^{-2}$, %BF = 17.8; Lan et al. (14): BMI = 27.4 $kg \cdot m^{-2}$, %BF = 21.0), the changes in body composition may be due to the increased training demands commonly seen during fire academies of similar duration. However, the contrasting changes in BM across the academy by Cornell et al. (15) may be attributed to the differences in exercise routines used by each academy. For example, Cornell et al. (15) reported recruits completed structured training throughout the duration of the academy that included both aerobic (2.5-mile run; two to three times per week) and resistance exercise (two to three times per week; three sets of eight to ten repetitions; 60%–80% 1RM). However, in the current study, recruits had physical training (~1 h, three times per week) from weeks 1 to 11; though, from weeks 12 to 32, recruits primarily completed field and occupation-specific training with only occasional and nonstructured physical training. These differences in training strategies may also explain the plateau in FFM, %BF, and FM from W15 to W30 of the academy. It is possible that the lack of significant changes is due to the lower exercise training volume used from W15 to W30 of the academy.

Cardiorespiratory Fitness

The results of the current study indicated that CRF (i.e., estimated $\dot{V}O_{2max}$) was significantly improved at both W15 and W30 of the training academy when compared to W1 of the academy. However, there was no significant change in estimated $\dot{V}O_{2max}$ between W15 and W30 of the academy. Previous literature has also shown improvements in CRF across firefighter training academies (~16 wk) (14,15,17). For example, Cornell et al. (15) and Gnacinski et al. (17) reported a 16.5% to 28.0% increase in estimated $\dot{V}O_{2max}$ from baseline to the end of a 14- and 16-wk academy, respectively. Further, Lan et al. (14) reported a 9.8% decrease in 1.5-mile run time (proxy for aerobic fitness) across their ~16-wk academy. Interestingly, Gnacinski et al. (17) reported a 16.5% increase in estimated $\dot{V}O_{2max}$ from week 1 to the midpoint (week 8) of the academy; however, $\dot{V}O_{2max}$ plateaued from the midpoint to the end of the academy (week 16) which is similar to the findings reported in our current study. It is possible the plateau in CRF from W15 to W30 of the training academy may be due to a shift from more structured physical training including aerobic exercise to a larger focus on field work and occupationally relevant tasks in the remaining weeks of the academy. Given that previous literature has shown aerobic fitness is an important predictor of firefighter performance (e.g., Candidate Physical Ability Test times) (12)) and risk factor for injuries (25), firefighter administrators may consider how these plateaus impact firefighter fitness and health in the academy and beyond. For example, administrators may wish to determine if the CRF of their candidates is above the recommended ranges (~ 42 $mL \cdot kg^{-1} \cdot min^{-1}$) to ensure safe occupational performance (42) and account for potential decreases that occur soon into their probationary period (15). Lastly, it is important to note that our average estimated $\dot{V}O_{2max}$ data ranged from 52.6 to 56.4 $mL \cdot kg^{-1} \cdot min^{-1}$ across the academy, which is higher than those reported by previous studies (15,29,43) in recruits and active-duty firefighters.

Muscle Strength and Vertical Jump Performance

The results from the current study revealed that UB PF remained unchanged from the W1 to W15 of the academy, but decreased at W30 of the academy. Previous work evaluating changes in UB strength in firefighters has reported mixed findings. For instance, Cornell et al. (15) reported no changes in handgrip strength, but a 9.0% increase in bench press strength from baseline to the end of their 14-wk academy. These contrasting findings in UB strength changes may be due to differences in 1) academy duration and testing timepoints (e.g., 14 wk vs 32 wk), 2) mode of UB strength assessments (e.g., upright row vs handgrip vs bench press), and/or 3) training strategies (e.g., bodyweight exercises vs structured resistance exercise) throughout the academy. It is unclear why UB PF plateaued from W1 to W15 and then decreased at W30. However, it is possible this may be due to the use of body weight exercises focusing on improving UB muscular endurance versus UB strength during the beginning of the academy and the tapering of physical training during the remainder of the academy as fire training became the focus.

The present study also indicated that LE strength improved from baseline to W15 and W30 of the academy, but there were no significant improvements from W15 to W30. Leg flexion strength at W1 was significantly greater than W15 and W30 of the academy, but there were no significant changes from the W15 to W30 of the academy. Cornell et al. (15) reported an increase in estimated one repetition maximum strength for the back squat exercise across a 14-wk academy. These findings (15) are similar to the improvements in LE strength in the current study, yet contrasts the decrease in LF strength.

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Although speculative, the contrasting findings for LF strength could be the result of body weight squats used as the primary lower-body exercise in the circuit training, which have been shown to activate the leg flexors less than the extensors (44). The unique responses in LE and LF strength resulted in a significant decrease in the H/Q ratio at both W15 and W30 of the academy when compared with baseline. Previous studies have suggested that a reduction in the H/Q ratio is a risk factor for hamstring and/or knee injury (20–22). The decrease in H/Q ratio at W30 of the academy in the present study may increase the risk of lower body musculoskeletal injuries in recruits as they transition into their probationary period as active-duty career firefighters. Implementing exercises specifically targeting the hamstring musculature (e.g., Romanian deadlift, Nordic hamstring curl) may improve H/Q ratios and reduce future hamstring and/or knee injury risk. Lastly, it is important to note that previous studies more commonly use dynamic isokinetic muscle actions (e.g., 30–300°$\cdot$s^{-1}) to examine conventional and functional H/Q ratios and the ability of H/Q ratios to predict lower extremity injuries specifically across fire academies requires future study (45).

The current study reported no significant changes in VJ performance (i.e., average power and jump height) across the academy, which is supported by the lack of significant changes in jump height or power reported by Cornell et al. (15). The lack of changes in VJ performance may be due to the absence of exercises included in training to specifically improve lower body power output (15). Given previous studies (11,46) have demonstrated lower body power output is associated with many critical and essential firefighter tasks (i.e., SC, rescue drag, charged hose advance), it may be important for future training academies to include exercise routines (e.g., resistance and plyometric training) previously shown to positively impact VJ performance (47).

Low Back Endurance and Balance Performance

Low back pain is one of the leading causes of lost work time among firefighters and is influenced by low back muscle endurance (6,23,48,49). The current study demonstrated no significant changes in lower back endurance during the fire academy. While we are unaware of other studies examining lower back endurance during the fire academy, these findings could be explained by the lack of physical training specifically targeting the core musculature. For instance, Mayer et al. (23) demonstrated a 24-wk worksite exercise program targeting the core (i.e., cat camel, birddog, curl-up, side bridge) and back (i.e., variable angle Roman chair) muscles significantly improved firefighter core muscle endurance, with no reports of the exercise intervention negatively affecting job performance for fire operations.

Previous studies have also suggested that balance may impact musculoskeletal injury rates in firefighters (40,50). In the present study, balance performance, specifically the composite score, posteromedial reach, and posterolateral reach were improved at both W15 and W30 of the academy. Based on previous work in firefighter recruits (27), the improvements in balance performance across the academy may be linked to the positive changes in %BF and LE strength in the current study.

Stair Climb Performance

Although previous studies have examined predictors of SC performance in firefighters (11,28,39), we are aware no previous studies that have examined changes in SC time across the academy. The findings of the current study indicated that SC time improved from W1 to W15 of the academy, but there were no significant improvements from W15 to W30 of the academy. Based on the results of the current study and others (11,28,39), the improvements in SC time may be linked to changes in CRF, %BF, thigh muscle quality, lower extremity strength, power, and/or steadiness.

Limitations

It is important to discuss our limitations. We examined health, fitness, and simulated occupational performance changes across a 32-wk academy in 19 firefighter recruits. Of note, training academies may significantly vary in duration, thus is it unclear how these changes may be generalizable to other training academies. Further, it is important to mention that we performed our testing sessions at the beginning (W1), midpoint (W15), and end (W30) of the academy to be consistent with previous studies examining changes across a academies (17–19). However, future studies may wish to have mid-academy testing occurring when training priorities changed (e.g., W12 in the current study). Further, due to the limited availability for all recruits to visit our lab for testing, we were only able to include a single measure of occupational performance. Future work may wish to include additional assessments that include a broader range of job task simulations. Lastly, future studies with larger samples are needed to determine which specific health and fitness variables may contribute to changes in simulated occupational performance across academies.

CONCLUSIONS

In summary, the findings of the current study indicated that the fire academy improved body composition, balance, CRF, LE strength, and SC performance from W1 to W15, which then plateaued at W30. The H/Q ratio and LF strength decreased from W1 to W15 and then plateaued at W30. Upper body strength was similar at W1 and W15, but decreased at W30. However, no significant changes occurred across the academy for VJ performance or lower back endurance. These results are impactful as they expand on previous studies (14,15) by examining longitudinal changes in health, fitness, and occupational performance of firefighter recruits at three timepoints across the fire academy. The findings of this investigation may also be helpful for fire administrators and tactical health and fitness professionals who may contribute to fire academy physical training recommendations.

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