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Effect of cardiorespiratory fitness level on physiological responses and task performance during a high-rise firefighting task

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Clinical significance

This study demonstrated that firefighters with cardiorespiratory fitness (CRF) levels at or above the national minimum standard, had a faster completion time and lower levels of perceived exertion, perceptions of thermal discomfort and air usage from a self-contained breathing apparatus, during a protracted and physically demanding high-rise firefighting task. Additionally, there was evidence to suggest that fitter firefighters experienced less cardiovascular strain after taking short rest breaks at regular intervals during the ascent phase.

Abstract

Objectives: To determine the impact of cardiorespiratory fitness (CRF) on physiological and performance outcomes during a 120-m vertical high-rise ascent in firefighters with CRF levels at or above (higher-fit (HF)) and below (lower-fit (LF)) the national recommended minimum physical employment standard ($\dot{V}O_2$max 42.3 $ml \cdot kg^{-1} \cdot min^{-1}$). **Methods:** Twenty-eight firefighters completed two high-rise firefighting trials (continuous and discontinuous ascent with pre-determined 1-min rest breaks). Task time (TT), heart rate (HR), ratings of perceived exertion (RPE), core body temperature (CT) and thermal comfort (TC) were recorded at predetermined elevations. **Results:** TT was significantly longer in both trials for the LF group. RPE and TC were also significantly higher in the LF group, with three times more LF firefighters being unable to complete the ascent without sounding their low-air alarm. **Conclusions:** Higher CRF improves performance and efficiency during stair-climbing in simulated high-rise firefighting tasks.

Keywords: Cardiorespiratory fitness, firefighters, high-rise, physical exertion.

Learning objectives

After reading this article, the learner will be better able to:

- Understand the importance of cardiorespiratory fitness (CRF) for fighting performance and for firefighter safety.
- Identify the impact of CRF on task performance and physiological and perceptual variables.
- Identify the impact that CRF has on air usage and its impact on task completion times.
- Understand the impact that CRF has on recovery when firefighters are given short rest breaks during a demanding firefighting incident.

Introduction

Firefighters perform a range of physically demanding occupational tasks in time-critical situations to prevent the spread of fire and to protect the public (1, 2). Such tasks require that workers possess appropriate levels of physical fitness to undertake this work safely and effectively. Numerous studies have demonstrated that greater amounts of cardiorespiratory fitness (CRF) (3-7), muscular strength and endurance (4, 7-11) and anaerobic power (5-7, 10, 12) are associated with improved firefighting performance. Consequently, minimum physical employment standards (PES) and associated tests are often mandated by employers to ensure the initial and ongoing (i.e., annual) physical fitness of operational personnel (8, 13-17).

Substandard physical fitness can impact individual and team performance during emergency situations jeopardising the safety of firefighters, their colleagues and the public. In particular, low levels of CRF are associated with increased injury (18, 19), and cardiovascular disease risk (20-22) in firefighters. Furthermore, when self-contained breathing apparatus (SCBA) is worn, a firefighter's ability to undertake work in these situations is limited by a finite amount of air in their SCBA (23-26). Firefighters with lower CRF levels have been shown to demonstrate reduced ventilatory efficiency (27) and use more air at a given work intensity (28) or overall during a set occupational task (29), thus reducing their duration and capability to perform potentially lifesaving work. This may be particularly important during some of the most physically demanding operational tasks, including high-rise firefighting (30).

To date, no studies have compared the physiological responses and performance outcomes of firefighters with levels of CRF above and below the minimum recommended

PES for UK firefighters. Therefore, the aim of this study was to compare a range of operational (task completion time (TT), time to low-air alarm (LAA)), physiological (heart rate (HR), core body temperature (CT)) and perceptual (ratings of perceived exertion (RPE), thermal comfort (TC)) outcomes in firefighters with CRF levels at or above and below the national recommended minimum cardiorespiratory PES for UK firefighters ($\dot{V}O_2$max 42.3 $ml \cdot kg^{-1} \cdot min^{-1}$), during a simulated high-rise firefighting task.

A secondary aim was to assess the influence of CRF level on the physiological and perceptual variables during a discontinuous high-rise firefighting task with short recovery breaks to identify if recover rates during the breaks were different between the groups. Our primary hypotheses were that TT, HR and RPE would be greater among firefighters below the minimum recommended PES, and that recovery would be slower following rest breaks during the discontinuous ascent.

Materials and Methods

Participants

Twenty-eight UK firefighters (17 male, 11 female) were recruited via internal advertisement and volunteered to participate in the trial. All participants were considered medically fit for operational duties and provided informed written consent. To compare the effect of fitness, participants were divided into two groups according to their CRF level measured during the preliminary assessments. Those participants with a $\dot{V}O_2$max of less than 42.3 $ml \cdot kg^{-1} \cdot min^{-1}$ (n = 11, 5 male, 6 female) were termed the lower fit (LF) group whilst those with a $\dot{V}O_2$max of 42.3 $ml \cdot kg^{-1} \cdot min^{-1}$ or above (n = 17, 12 male, 5 female) were termed the higher fit (HF) group. The study was approved by the University of Bath's Research Ethics Approval Committee for Health (REACH EP 19/20 098). This study was conducted in

accordance with the EQUATER Network Reporting Guidelines (STROBE) (31) (see checklist, Supplemental Digital Content, http://links.lww.com/JOM/B548). Participant demographics are presented in table 1.

Experimental design

The main trials were conducted at a 62-floor (278-m) commercial building in central London in January 2021. Each floor of the building had 24 steps and a vertical elevation of 4-m. The stairwell temperature was maintained at ~20ºC. Preliminary assessments were conducted at a nearby fire station in January 2021 and included: stature (cm), body mass (kg), estimated body fat percentage using skinfold thickness (Seca, Germany) at 4-sites (32), and an incremental walking or running treadmill test to volitional exhaustion to determine $\dot{V}O_2$ max lasting 9-15 minutes (Cosmed K5, Italy).

Participants were randomly assigned to complete two trials in a single day under different experimental conditions (a continuous ascent and discontinuous ascent (i.e., with rest breaks). Each trial consisted of a 30-floor (120-m) ascent and subsequent descent of a continuous stairwell. Participants were not given any instruction to how to ascend the stairs (i.e., climbing technique). When on the continuous ascent trial, experimental measures were recorded immediately prior to starting the ascent (0-m) and then immediately after arriving at the 40-, 80-, 100-, 120-m and then descending fully to the finish (0-m) points. When on the discontinuous ascent trial, participants took a timed 1-min break at the 40-, 80-, 100-, 120-m points with experimental measures being recorded immediately prior to starting the ascent (0-m) and immediately following the 1-min rest break at the 40-, 80, 100-m points and then immediately on arriving at the 120-m and the finish (0-m) point.

Each participant was provided at least 2 hours recovery between trials by resting in a seated area whilst consuming a packed lunch and room temperature bottled water until HR and CT had returned to normal. During all trials, participants wore full structural firefighting PPE, consisting of standard issue workwear, tunic, leggings, flash hood, gloves, helmet, boots and torch weighing 10.6 kg in addition to a standard duration breathing apparatus SDBA weighing 14.0 kg. All BA cylinders were charged to 270 bars prior to use. Participants completed all trials with their face masks on and their air supply turned on. Each BA was fitted with a standard LAA, which sounded at 70 (±5) bars.

Participants also carried a standardised door enforcer tool (Sigma Security Devices, UK) weighing 14.1 kg during the ascent phase only. The enforcer was agreed to be a representative item of equipment that a firefighter may be required to transport during such an operational scenario. Participants were asked to complete each trial as fast as possible, i.e., as if it were an emergency, whilst adhering to standard operating procedures. A safety officer walked behind each participant throughout the trials with a research assistant situated at various elevation points to document the experimental measures of participants.

Experimental measures

Two hours prior to the trials starting, participants were asked to swallow a coded telemetry pill (CorTemp, HQ Inc., US) with room temperature water and instructed not to consume any further fluids until after their first trial. This was to prevent any short-term effects of ingested beverage temperature on sensor measurements (33). The CorTemp logger was placed in a standard issue fire service radio pouch, which was set to record CT at 20 second (sec) intervals throughout the trials. Participants with a recorded CT of $\geq$ 39.5ºC were stopped from continuing immediately and a cooling strategy (tunic and helmet removal,

water consumption and radial forearm cooling with immersion in cold tap water, approximately 10 ºC) was initiated until CT had reduced to safe limits (i.e., < 38.5ºC).

Each participant was also fitted with a HR chest strap (Polar Electro Oy, Finland). HR was recorded at 20 sec intervals. Both the CorTemp logger and Polar wristwatch were fitted to the outside of the tunic in order that both CT and HR could be easily monitored and recorded at the designated elevation points. These points were at the start of the trial (start, 0-m), at 40-, 80-, 100- and 120-m of vertical elevation and then following a full descent of the stairs back to the start point (finish, 0-m). Participants were also asked to report their rating of perceived exertion (RPE) using the 6-20 Borg scale (34) and perception of thermal comfort (TC) on a 9-point Likert scale from 'very cold' to 'very hot' at these points (35). Finally, task performance defined as TT in min:sec to reach the 40, 80, 100 and 120-m of vertical elevation and to the finish point (0-m) was recorded using a stopwatch monitored by the safety officers.

Statistical analyses

All statistical analyses were completed using IBM SPSS version 28 (IBM, New York, USA). Descriptive data were calculated for all variables, at each elevation point, for each trial and are presented as mean ± standard deviation (SD), unless otherwise stated. A two-way mixed ANOVA was used to analyse the interaction and main effects of CRF groups and elevation point on TT, HR, CT, RPE and TC. Partial eta-squared (η_p^2) was used to calculate the standardised effect size where an effect size of 0.01 is considered small, 0.06 moderate and 0.14 or above large. Where the assumption of sphericity was violated, a Greenhouse-Geisser correction was applied.

An independent sample t-test (with a Bonferroni correction to adjust for family-wise error rate) was used to identify simple main effect differences between groups, where an interaction effect was observed. Ninety-five percent confidence intervals were calculated when reporting a significant main effect difference between fitness groups (36). Hedges' g was used to calculate the standardised effect sizes in the analysis of simple main effects where an effect size of 0.2 is considered small, 0.5 moderate and 0.8 or above large (37). Fishers Freeman-Halton exact test was used to determine if there was a difference between the fitness groups in the distribution at the point in which firefighters activated their LAA. A chi-squared test was used to identify any differences between the categorical variables during a post-hoc analysis. A long-run error rate of 5% (alpha = 0.05) was set *a priori* such that $p <$ 0.05 was deemed statistically significant. Exact p-values are given unless $p < .001$.

Results

Continuous ascent

Effect of CRF on TT

During the continuous ascent, TT to complete the trial was 21:07 (± 04:19) min:sec in the HF group and 25:09 (± 03:32) min:sec in the LF group. There was a significant interaction between CRF and elevation for TT, (F (1.41, 36.6) = 5.79, p = .013, η_p^2 = 0.18 with CRF having a significant effect on TT at the 40-, 80-, 100-, 120-m and the finish (0-m) points (figure 1). Mean TT for participants in the LF group was 00:52 (± 00:48) min:sec slower to 40-m [t(26) = 3.97, p = < .001, g = 1.49], 02:05 (± 02:20) min:sec slower to 80-m [t(26) = 3.20, p = .01, g = 1.20], 02:44 (± 03:07) min:sec slower to 100-m [t(26) = 3.10, p = .01, g = 1.17], 03:15 (± 03:48) min:sec slower to 120-m [t(26) = 3.03, p = .01, g = 1.14] and 04:01 (± 05:35) min:sec slower to the finish (0-m) point [t(26) = 2.57, p = .04, g = 0.97].

Effect of CRF on HR

During the continuous ascent trial, participants in the LF group had a mean trial HR of 172 (± 10) and a peak HR of 180 (± 10) bpm compared to 174 (± 10) and 180 (± 9) bpm respectively in the HF group. There was no interaction effect between CRF and elevation for HR on the continuous ascent. Mean HR varied with elevation [$F(2.09, 54.3) = 550$, $p = < .001$, $\eta_p^2 = 0.96$], however there was not a statistically significant difference in mean HR between CRF groups [$F(1, 42) = 0.34$, $p = .564$, $\eta_p^2 = 0.01$].

Effect of CRF on RPE

During the continuous ascent trial, participants in the LF group had a mean trial RPE of 17.7 (± 1.6) and a peak RPE of 19.2 (± 0.9) compared to 16.6 (± 1.7) and 18.4 (± 1.4) in the HF group, respectively. There was no interaction effect between CRF and elevation for RPE on the continuous ascent. Mean RPE varied with elevation [$F(3.20, 83.2) = 359$, $p = < .001$, $\eta_p^2 = 0.93$] and there was a statistically significant difference in mean RPE between CRF groups [$F(1, 26) = 6.30$, $p = .019$, $\eta_p^2 = 0.20$] where participants in the LF group had a mean RPE score 1.1 (95% CI, 0.19 to 1.92) points higher than the HF group.

Effect of CRF on TC

During the continuous ascent trial, participants in the LF group had a mean trial TC score of 8.2 (± 0.8) and a peak TC score of 8.7 (± 0.5) compared to 7.6 (± 0.9) and 8.1 (± 0.9) respectively in the HF group. There was no interaction effect between CRF and elevation for TC on the continuous ascent. Mean TC varied with elevation [$F(2.52, 65.5) = 120$, $p = < .001$, $\eta_p^2 = 0.82$], however, there was not a statistically significant difference in mean TC between CRF groups [$F(1, 26) = 3.42$, $p = .076$, $\eta_p^2 = 0.12$].

Effect of CRF on CT

During the continuous ascent, participants in the LF group had a mean trial CT of 37.9ºC (± 0.5) and a peak CT of 38.3ºC (± 0.5) compared to 38.0ºC (± 0.5) and 38.5ºC (± 0.5) respectively in the HF group. There was no interaction effect between CRF and elevation for CT on the continuous ascent. Mean CT varied with elevation [F(2.13, 55.3) = 196, p = < .001, η_p^2 = 0.88], however there was not a statistically significant difference in mean CT between CRF groups [F(1, 26) = 0.92, p = .76, η_p^2 = 0.00].

Discontinuous ascent

Effect of CRF on TT

TT to complete the trial was 22:29 (± 03:06) min:sec in the HF group and 26:31 (± 03:13) min:sec in the LF group. There was a significant interaction between CRF and elevation for TT [F (1.26, 32.6) = 9.15, p = .003, η_p^2 = 0.26] with CRF having a statistically significant effect on TT. Mean TT for participants in the LF group was 00:51 (± 00:56) min:sec slower to 40-m [t(26) = 3.49, p = < .001, g = 1.31], 01:54 (± 01:46) min:sec slower to 80-m [t(26) = 3.97, p = < .001, g = 1.49], 02:25 (± 02:41) min:sec slower to 100-m [t(26) = 3.28, p = .01, g = 1.23], 03:10 (± 03:36) min:sec slower to 120-m [t(26) = 3.24, p = .01, g = 1.22] and 04:02 (± 04:28) min:sec slower to the final (0 m) point [t(26) = 3.31, p = .01, g = 1.24].

Effect of CRF on HR

Participants in the LF group had a mean trial HR of 162 (± 11) and a peak HR of 181 (± 10) bpm compared to 162 (± 12) and 179 (± 11) bpm respectively in the HF group. There was a significant interaction between CRF and elevation for HR [F (3.16, 82.2) = 2.92, p =

.036, η_p^2 = 0.10], however, the effects of CRF did not have a statistically significant effect on HR at any specific elevation point.

Effect of CRF on RPE

Participants in the LF group had a mean trial RPE of 17.6 (± 1.4) and a peak RPE of 19.5 (± 0.9) compared to 16.0 (± 2.0) and 18.3 (± 1.5) respectively in the HF group. There was a significant interaction between CRF and elevation for RPE [F (3.29, 85.6) = 3.30, p = .021, η_p^2 = 0.11], with CRF having a significant effect on RPE at the 80-, 100- and 120-m elevation points. Mean RPE for participants in the LF group was 0.2 (± 1.4) higher at the start (0-m) [t(26) = 0.57, p = .99, g = 0.21], 1.5 (± 2.8) higher at 40-m [t(26) = 1.93, p = .19, g = 0.73], 2.5 (± 2.7) higher at 80-m [t(26) = 3.29, p = .01, g = 1.23], 2.3 (± 2.6) higher at 100-m [t(26) = 2.93, p = .02, g = 1.10], 1.2 (± 1.8) higher at 120-m [t(26) = 2.53, p = .05, g = 0.86] and 0.6 (± 2.5) higher at the finish (0-m) point [t(26) = 0.93, p = .99, g = 0.35].

Effect of CRF on TC

Participants in the LF group had a mean trial TC score of 8.1 (± 0.9) and a peak TC score of 8.6 (± 0.7) compared to 7.2 (± 0.8) and 7.9 (± 0.8) respectively in the HF group. There was no interaction effect between CRF and elevation for TC on the discontinuous ascent. Mean TC varied with elevation [F(1.82, 47.2) = 94.6, p = < .001, η_p^2 = 0.78] and there was a significant difference in mean TC between CRF groups [F(1, 26) = 7.40, p = .011, η_p^2 = 0.22], where participants in the LF group had a mean TC score 0.66 (95% CI, 0.16 to 1.16) points higher than the HF group.

Effect of CRF on CT

Participants in the LF group had a mean trial CT of 38.0ºC (± 0.5) and a peak TC score of 38.5ºC (± 0.5) compared to 37.9ºC (± 0.5) and 38.5ºC (± 0.5) respectively in the HF group. There was a significant interaction between CRF and elevation for CT [F (1.54, 40.0) = 4.12, p = .033, η_p^2 = 0.14], however the effects of CRF did not have a statistically significant effect on CT at any specific elevation point.

Air Supply

During the continuous ascent, 5 participants in the LF group and 2 participants in the HF group activated their LAA on the ascent phase. During the descent phase 4 participants in the LF group and 13 participants in the HF group activated their LAA. Two participants in both the LF and HF groups did not activate their LAA before completing the trial. There was not a statistically significant difference between the LF and HF groups in the distribution of participants activating their LAA (p = .074, V = 0.42).

During the discontinuous ascent, 6 participants in the LF group and 2 participants in the HF group activated their LAA on the ascent phase of the trial. During the descent phase 4 participants in the LF group and 15 participants in the HF group activated their LAA. One participant in the LF group did not activate their LAA before completing the trial. There was a statistically significant difference between the LF and HF groups in the distribution of participants activating their LAA (p = .015, V = 0.55). A post-hoc analysis of firefighters activating their LAA alarm on the ascent or descent revealed that there were significantly fewer firefighters activating their LAA on the ascent in the HF group when compared to the LF group (X^2 (1, 27) = 7.03, p = .008, V = 5.10). Figure 4 shows the proportion of participants activating their LAA during the trials.

Discussion

The aim of this study was to compare a range of operational, physiological and perceptual outcomes in firefighters with CRF levels at or above and below the national recommended minimum cardiorespiratory PES for UK firefighters, during a simulated high-rise firefighting task. A secondary aim was to assess whether there were any differences between groups when completing the task continuously versus discontinuously. As expected, both trials were extremely physically demanding with high mean and peak HR along with high RPE and TC throughout the trial. These results are similar to other work reporting high-rise firefighting as one of the most physically demanding roles performed by firefighters (13, 24, 30, 38).

During both trials, the group mean TT data identified that the LF group were significantly slower to each elevation point, losing approximately 1 min in time for every 40-m of elevation ascended and every 120-m descended, when compared to the HF group. This resulted in the LF group being approximately 3 min slower to the top of the 120-m ascent and 4 min slower to complete the entire task. The effect sizes were also large at each of the elevation points indicating the practical significance of these time differences between the groups. Considering other studies have demonstrated the relationship between task performance and CRF (9, 10, 39), this outcome is not unexpected. However, these results quantify the difference in task performances between the LF and HF groups during a highly physically demanding and protracted simulated incident providing potentially valuable insight into the impact of substandard levels of CRF on the fireground.

During the continuous trial no significant group mean differences in HR were observed between the HF and LF groups and this is most likely because participants were

instructed to complete the task as fast as possible. However, this may have been different if participants were instructed to work at a set rate. In contrast, group mean RPE were significantly different between fitness groups during both trials. In the continuous ascent, mean RPE was on average 1.1 points lower in the HF group indicating that these participants perceived themselves to be under less physical strain than the LF group, despite there being no difference in HR responses between the groups. This change in perceived exertion with improvements in CRF is consistent with other studies in both moderately and highly trained individuals (40) and also when comparing lower and higher fit groups of firefighters in other studies (29), however some controversy still remains as to whether RPE at similar workloads is affected by CRF level (40). During the discontinuous ascent, mean RPE was significantly and meaningfully lower in the HF group at the 80-, 100- and 120-m elevation points compared to the LF group. As CRF is associated with improved heart rate recovery (41) and removal of metabolic bi-products, it is plausible that during the 1 min rest break at 80 and 100-m, the HF group were able to recover more quickly than the LF group which translated into the larger differences in group mean RPE at these elevation points.

Group mean CT was not different between the LF and HF groups during either trial. Whilst it is recognised that improved CRF can benefit heat tolerance, improve perceptions of thermal strain and slow the rate of heat storage in chronically trained individuals (42), there was no effect of CRF on CT in the present study. This may be because the firefighters in the HF group were not chronically trained. Group mean thermal comfort was not different between fitness groups during the continuous ascent trial. However, during the discontinuous ascent, mean TC score was 0.7 points lower in the HF group when compared to the LF group. As there were no differences in CT between groups, it is likely that TC is more related to RPE and there is evidence to suggest that the two indices are correlated in all but highly

trained individuals which may indicate why TC and RPE in both the LF and HF groups appear similar (43).

During the continuous ascent trial, almost half (45%) of the firefighters in the LF group consumed over 75% of their air from their SCBA, triggering their LAA during the ascent phase of the trial, suggesting that these firefighters would have had to turn back to safety and would have been unable to complete the task. This is compared to only 12% of participants in the HF group. The difference in air consumption between groups widened in the discontinuous ascent trial where over half (55%) of the firefighters in the LF group activated their LAA during the ascent phase compared with just 12% in the HF group, which is most likely attributed to the longer ascent time due to the breaks taken at the 40-, 80- and 100-m elevation points. Whilst it is recognised that CRF can improve ventilatory efficiency in firefighters (27), the impact of CRF on air consumption and task success rates has not been investigated until now. Previously, von Heimberg et al. (2006) reported that a less fit group of firefighters used approximately 20% more air during a simulated rescue task, although the authors noted that *"this was of little importance in the present study where the whole task completed in less than 10 minutes, but it could be very important in real life situations lasting 20 to 30 minutes or more"(p. 123)* (29).

Strengths and limitations

One of the broader strengths of this study is that it adds to the relative lack of data on the impact of CRF on physiological responses, task performance and success during a protracted and physically demanding urban firefighting task. This provides fire service managers and incident commanders a significant insight into the impact of low levels of fitness in firefighters and how this translates on the fireground. It may have been more useful

to categorise this group of firefighters into low moderate and high fitness groups as this may have provided more detailed information into the effects of CRF. However, this would have reduced the sample sizes in each group, which may have limited the ability to draw meaningful comparisons between them and because of this, this analysis was not undertaken. Another strength of this study is that we reported elevation in metres rather than in floors ascended allowing the findings of this study to be applied more broadly to any high-rise building. A potential limitation of this study, and one common to this type of research was that the simulation was not conducted under live fire conditions or in the heat. It is possible that the perceptual and physiological responses monitored during these tasks may have been different in a real emergency situation or where environmental heat and smoke were present.

Conclusions

This study highlights the importance of CRF during firefighting incidents. We hypothesised that that TT, HR and RPE would be greater among firefighters below the minimum recommended CRF standard. Whilst these simulated high-rise firefighting tasks were extremely physically demanding for all firefighters in this study, those in the HF group completed the tasks significantly quicker and with less perceived exertion and thermal discomfort than those in the LF group. Furthermore, the HF group were able to conduct greater amounts of work in their SCBA demonstrating the additional benefits that CRF brings to firefighting. Findings from the discontinuous ascent trial also highlighted the beneficial effects of CRF to recovery rates which may be beneficial during protracted firefighting incidents or even repeat exposures.

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Figure Legends

Figure 1. Mean (± SD) task time for the LF and HF groups during the continuous ascent.

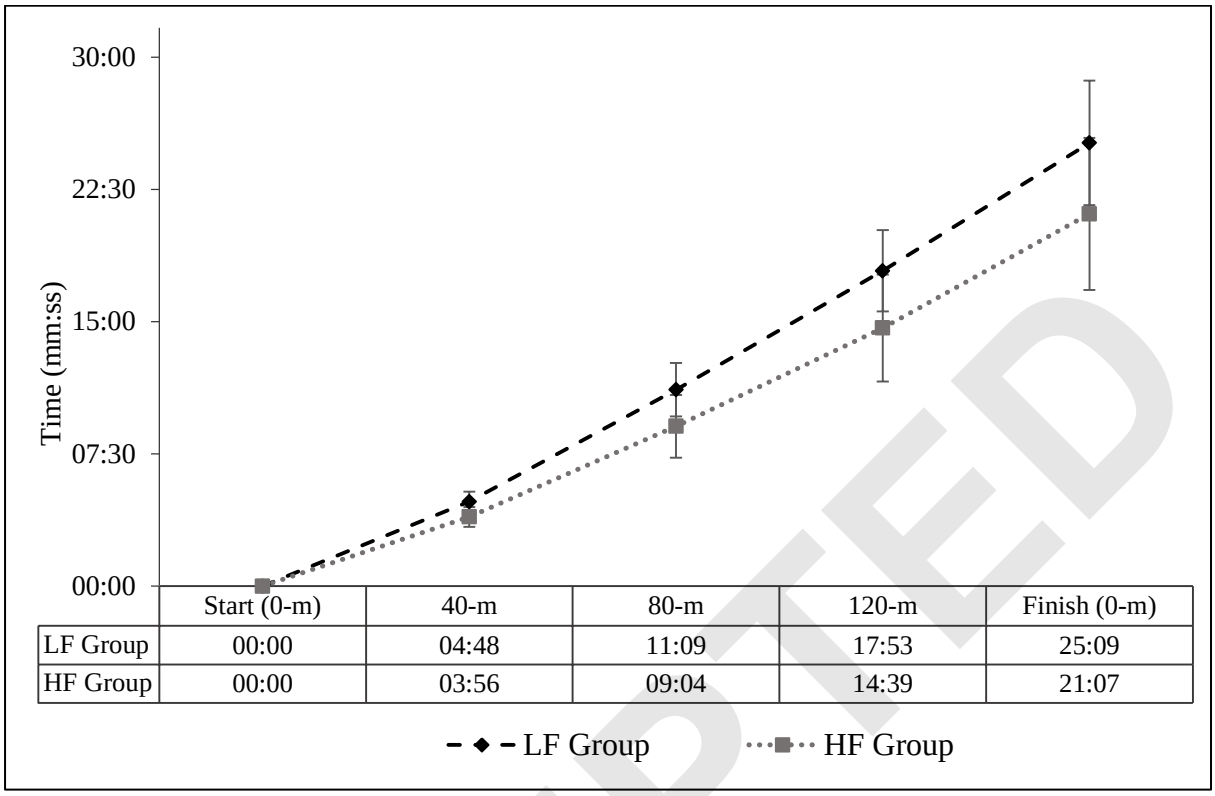
Figure 2. Mean (± SD) RPE for the LF and HF groups during the continuous ascent.

Figure 3. Mean (± SD) RPE for the LF and HF groups during the discontinuous ascent.

Figure 4. Mean (± SD) TC for the LF and HF groups during the discontinuous ascent.

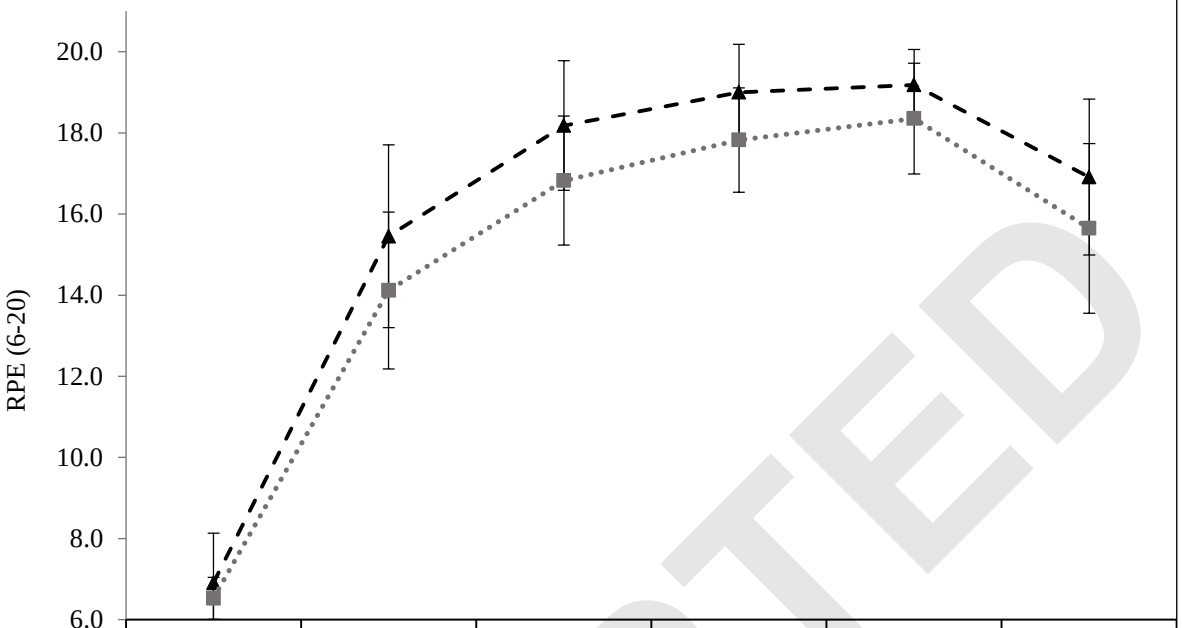
Figure 5. Proportion (%) of participants activating their LAA during the trials.

Figure 1



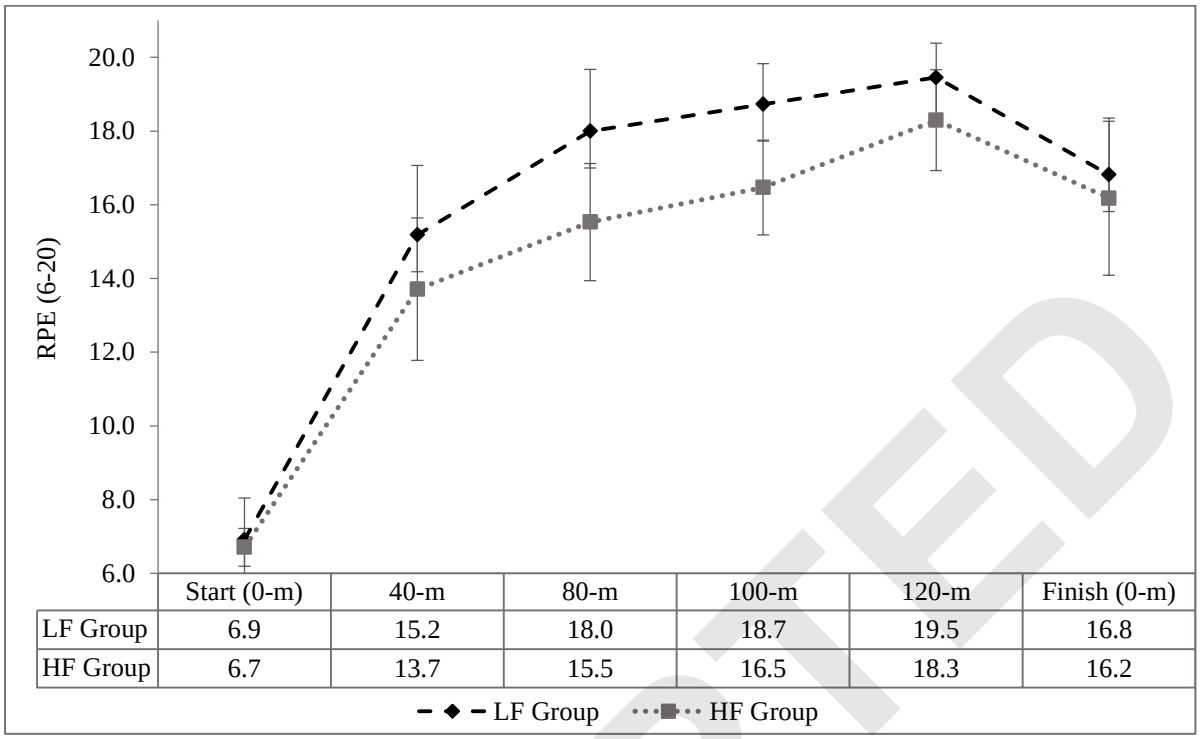
	Start (0-m)	40-m	80-m	120-m	Finish (0-m)
LF Group	00:00	04:48	11:09	17:53	25:09
HF Group	00:00	03:56	09:04	14:39	21:07

Figure 2



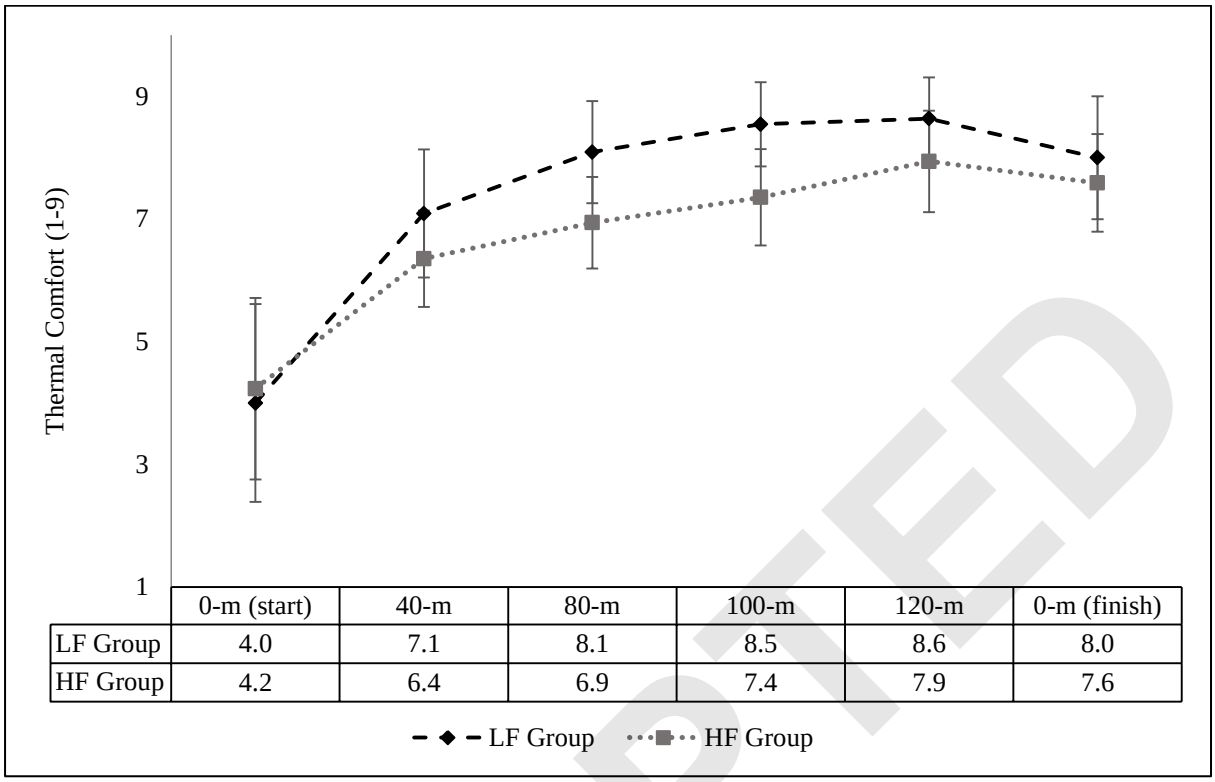
	Start (0-m)	40-m	80-m	100-m	120-m	Finish (0-m)
LF Group	6.9	15.5	18.2	19.0	19.2	16.9
HF Group	6.5	14.1	16.8	17.8	18.4	15.6

Figure 3



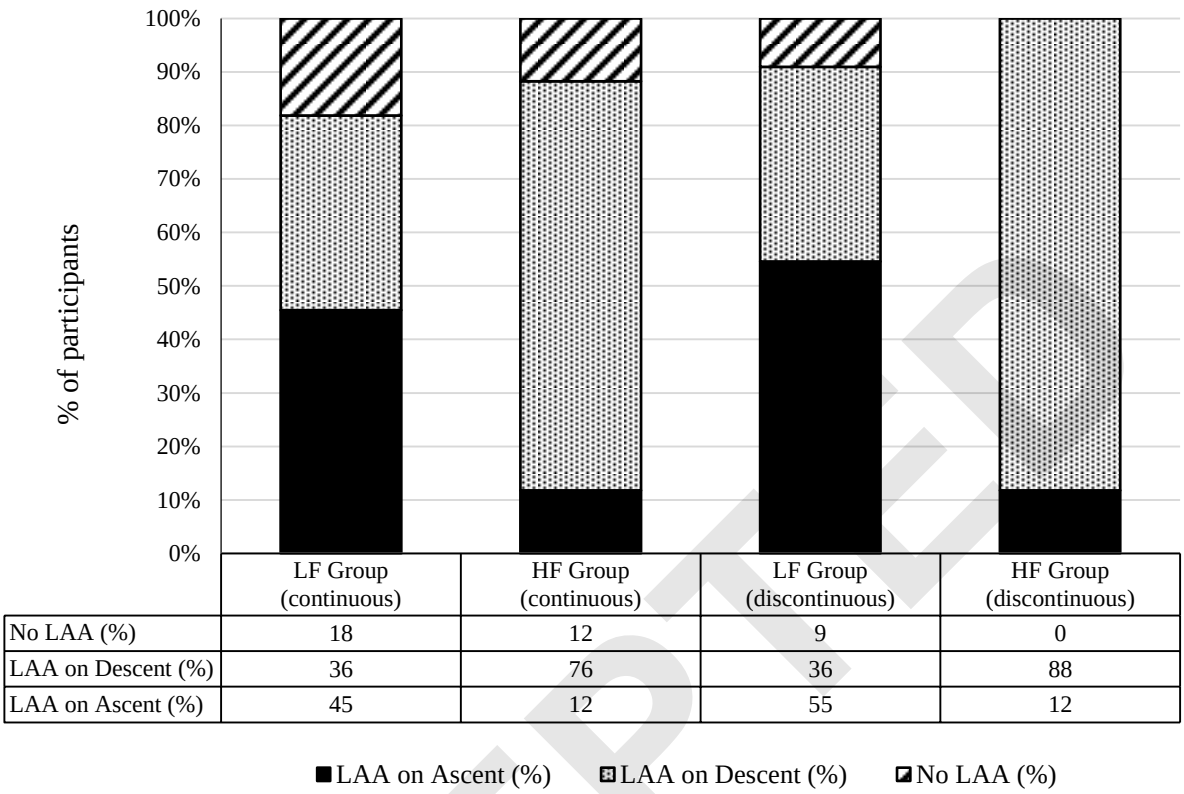
	Start (0-m)	40-m	80-m	100-m	120-m	Finish (0-m)
LF Group	6.9	15.2	18.0	18.7	19.5	16.8
HF Group	6.7	13.7	15.5	16.5	18.3	16.2

Figure 4



	0-m (start)	40-m	80-m	100-m	120-m	0-m (finish)
LF Group	4.0	7.1	8.1	8.5	8.6	8.0
HF Group	4.2	6.4	6.9	7.4	7.9	7.6

Figure 5



	LF Group (continuous)	HF Group (continuous)	LF Group (discontinuous)	HF Group (discontinuous)
No LAA (%)	18	12	9	0
LAA on Descent (%)	36	76	36	88
LAA on Ascent (%)	45	12	55	12

Table 1. Mean (± SD) participant demographics.

Variable	Participants				
	All	Male	Female	LF	HF
n	28	17	11	11	17
Age (years)	37 ± 9	39 ± 9	33.1 ± 7	37 ± 10	36 ± 8
Height (m)	175 ± 8	179 ± 6	169 ± 5.1	174 ± 10	176 ± 7
Body mass (kg)	80 ± 16	88.1 ± 14	67 ± 10	83 ± 20	77 ± 13
BMI ($kg \cdot m^2$)	25.8 ± 3.6	27.3 ± 3.3	23.4 ± 2.8	27.1 ± 4.3	24.9 ± 2.9
Estimated body fat (%)	24.0 ± 4.9	22.0 ± 3.8	26.8 ± 5.1	27.7 ± 4.1	21.6 ± 3.8*
$\dot{V}O_2max$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	43.9 ± 5.6	45.2 ± 6.0	41.8 ± 4.3	38.3 ± 2.8	47.5 ± 3.5*

*= significantly different from the LF group (< 42.3 $ml \cdot kg^{-1} \cdot min^{-1}$).

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	4-5
Methods			
Study design	4	Present key elements of study design early in the paper	6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	5
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	*7-8*
Bias	9	Describe any efforts to address potential sources of bias	7
Study size	10	Explain how the study size was arrived at	6
Quantitative	11	Explain how quantitative variables were handled in the analyses. If	8-9

variables		applicable, describe which groupings were chosen and why	
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8-9
		(*b*) Describe any methods used to examine subgroups and interactions	8-9
		(*c*) Explain how missing data were addressed	
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	5, 7-8
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	5
		(b) Indicate number of participants with missing data for each variable of interest	NA
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	NA
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	*NA*
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	*NA*
		Cross-sectional study—Report numbers of outcome events or summary measures	*NA*
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	9-16

		(*b*) Report category boundaries when continuous variables were categorized	9-16
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	9-16
Discussion			
Key results	18	Summarise key results with reference to study objectives	17
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	20
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	20
Generalisability	21	Discuss the generalisability (external validity) of the study results	19-20
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Title page

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.