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Systematic Review

The Metabolic Demand of Firefighting: A Systematic Review

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Abstract: Background: The aim of this systematic review was to collect, appraise, and synthesize the available information related to the cardiovascular and metabolic demands of commonly performed firefighting tasks while wearing personal protective equipment (PPE) inclusive of self-contained breathing apparatus (SCBA). **Methods**: Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, academic databases (PubMed, Embase, and SPORTDiscus databases) were searched for relevant records which were subjected to dedicated eligibility criteria with included articles quality appraised using the Critical Appraisal Skills Programme (CASP) checklist. **Results**: Of an initial 1463 identified records, 20 studies with a mean CASP of 8.26/11 informed the review. A myriad of varying field tests have been employed to determine physical preparedness and assess the metabolic demand of firefighting. **Conclusions**: The volume of evidence suggests that PPE and SCBA must be incorporated when assessing the demands of firefighting as they clearly increase the metabolic cost of combined simulated firefighting tasks. Although real-world scenarios are made up of a combination of individual firefighting tasks, there remains a clear need to determine the metabolic cost of isolated firefighting tasks such as forcible entry, hose drag, victim rescue, ladder raise, and stair climbing with and without PPE and SCBA. The quantification of the metabolic demand of these tasks may assist tactical trainers when designing simulated scenarios and training programs for firefighters.

Keywords: cardiorespiratory fitness; occupational performance; SCBA; CPAT; METS; firefighter

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1. Introduction

Firefighting is an occupation known for its extreme physiological and psychological demands in challenging environments [1–5]. Upon arriving at the scene of an emergency, firefighters may be required to perform heavy lifting, carry and drag working tools (e.g., sledgehammers, chainsaws, hoses, etc.), and rescue victims [4,6]. To perform their duties safely, firefighters must wear personal protective equipment (PPE). This PPE includes fire-retardant bunker gear, a helmet with face shield, and insulated gloves that protect them from thermal environments that can reach extremely high temperatures [6]. In addition, firefighters wear a self-contained breathing apparatus (SCBA) that protects them from toxic gases and hazardous particles. The full firefighting ensemble weighs approximately

25 kg [4,7]. This additional weight, combined with the weight of their working tools, directly influences the physical demands associated with performing essential job tasks [1,8,9].

In order to withstand the physical rigors associated with firefighting, it is generally accepted that a certain level of fitness is required [10]. According to the National Fire Protection Association (NFPA) [11], firefighters must portray cardiorespiratory fitness levels above the 35th percentile for the general population, based on the American College of Sports Medicine guidelines, with values above the 50th percentile being considered desirable [11]. When adjusting by age and sex, the minimum metabolic equivalent (METS) values (35th percentile) for males range from 12.4 (age 20–29) to 7.3 (age 60–69), and those for females range from 9.6 (age 20–29) to 5.3 (age 60–69). Firefighters unable to meet these standards may not only be less effective in their jobs but also may be more likely to experience a cardiovascular incident when compared to their fitter counterparts [12]. Supporting this assertion, figures based on the 2022 NFPA report found that on-duty sudden cardiac arrests accounted for 43% of all firefighter fatalities from 2011 to 2021 [13]. Most of these fatalities occurred because of strenuous or stressful physical activity while on duty [12]. Consequently, determining the range of cardiorespiratory and metabolic demands associated with various fire suppression tasks may aid in the development of physical training programs to help firefighters tolerate the cardiovascular strain while on duty.

Numerous investigations have sought to quantify the physical demands of performing firefighting tasks. However, due to the unpredictability and the risks associated with measuring these demands during live fire situations, job simulation tasks are often performed and measured in laboratory-based settings. Furthermore, many of these tasks are performed while wearing normal athletic apparel and in the absence of PPE or SCBA [4]. This may be problematic from a contextual standpoint, as the excess weight of the PPE and the additional breathing strain caused by the SCBA increases the metabolic demand of performing occupational tasks [14]. Consequently, firefighters may reach indicators of near-maximal exertion such as maximal heart rate (HR), lactate concentration, and cortisol [3,15] at a decreased relative rate of oxygen uptake (RVO_2) [6,16–18]. For example, Louhevaara et al. [7] reported that wearing a full firefighting ensemble (FFE) did not influence maximal HR despite an approximate 30% decrease in maximal peak VO_2 (46.9 to 34.1 $mL \cdot kg^{-1} \cdot min^{-1}$). Ensari et al. [16] also reported firefighters reaching near-maximal HR at 75% of RVO_{2max} during simulated tasks. As such, it may be assumed that PPE and SCBA will also affect the RVO_{2max} of firefighters.

Indeed, Perroni et al. [19,20] found a reduction of approximately 20% in firefighters' RVO_{2max} (54.4 ± 6.2 to 43.4 ± 5.7 $mL \cdot kg^{-1} \cdot min^{-1}$) while performing a submaximal VO_2 test with, compared to without, their PPE and SCBA. In another study, firefighters' RVO_{2max} decreased 17.3% when performing the test with PPE and SCBA [21]. These results were corroborated by Lee et al. [22]. In their study, they reported a decrease in RVO_{2max} of approximately 10% (46.7 ± 6.5 to 42.4 ± 9.0 $mL \cdot kg^{-1} \cdot min^{-1}$) while personnel wore FFE. It should be noted that their RVO_{2max} values were decreased even during the early stages of the VO_{2max} test, with a consistent decline that ranged from 8 to 12% when compared to the test performed with athletic clothing [22]. This decrease in capacity may lead to a potential risk of overestimating firefighters' true operational VO_2 capacity. Additionally, this may lead to a false assumption that the firefighters are not exercising at, or reaching, the recommended minimum cardiorespiratory fitness levels.

Although there is evidence of the link between the additional external load and its effects on the metabolic demands of firefighting [7,14,16,19–22], there appears to be a lack of standardization in testing procedures. Therefore, the aim of this systematic review was to identify, appraise and summarize the available research related to the metabolic demands

of commonly performed firefighting tasks while wearing PPE and SCBA. This information may be useful to fire agencies and physical fitness instructors when selecting testing and training drills to maintain physical fitness among firefighters.

2. Results

The search process performed in the three databases resulted in 1463 records. Upon removing duplicate articles (n = 13) and screening titles and abstracts, the full texts of 1450 records were excluded. The remaining 35 reports were read in their entirety and 20 of these were included in this review as they met the eligibility criteria previously described. The identification, screening and inclusion process is shown in a PRISMA diagram in Figure 1. The extracted data from the 20 studies included in this review and their respective quality mean scores are detailed in Table 1.

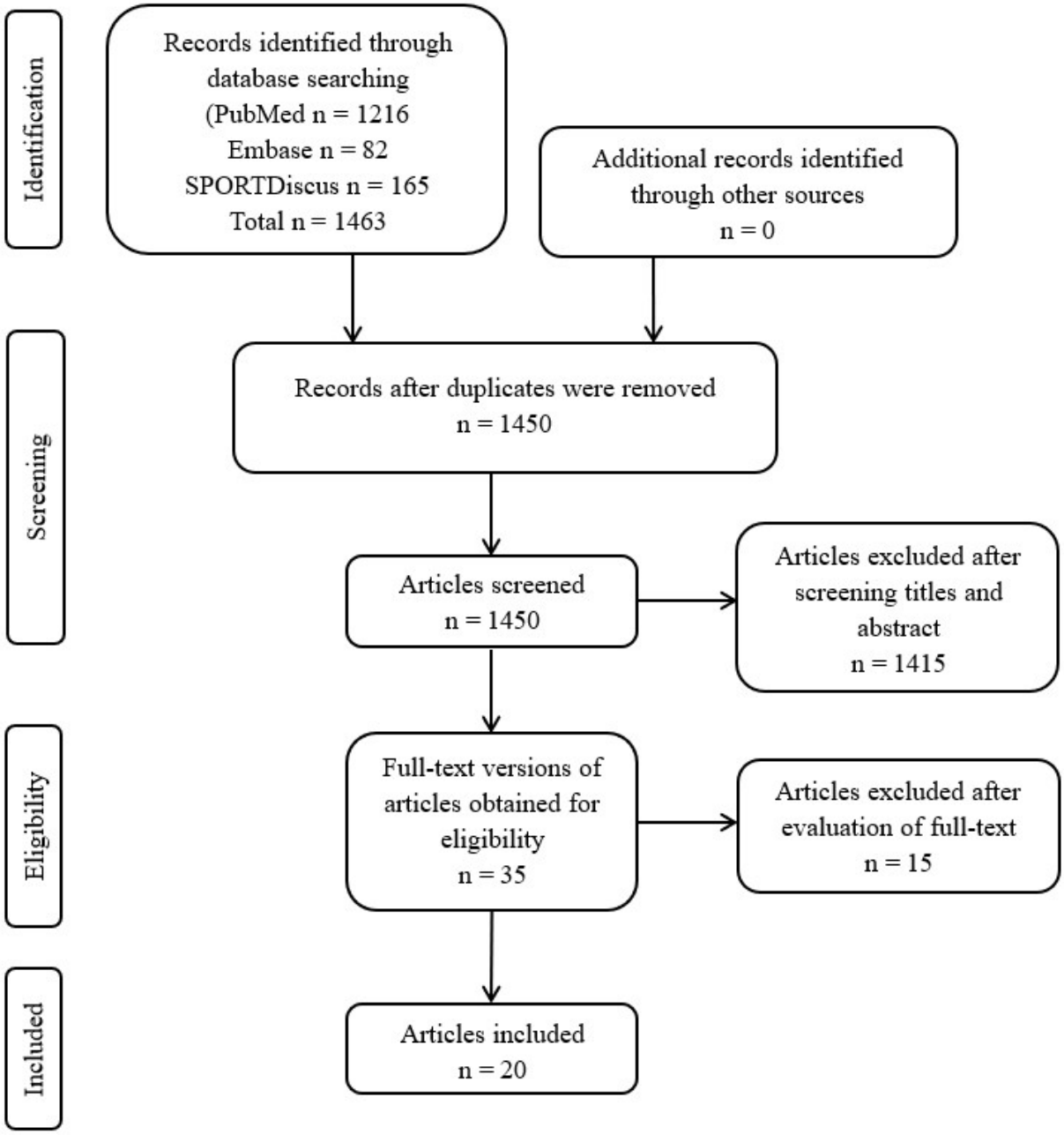


Figure 1. Register flow diagram of the search process.

Table 1. Summary of evaluated studies.

Author Population	Firefighting Tasks	Age (Years)	Time Duration (s)	Heart Rate (bpm)	Mean RVO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$)	Mean METS	CASP Score
Adams et al. 2009 23 healthy male firefighters	Full obstacle course **: 1. Ladder carry, raise, and extension (4.3 m foot ladder) 2. Forcible entry (used a 5.1 kg sledge hammer) 3. High-rise pack (carried a 26.8 kg high-rise hose for 5 floors) 4. Hand line advancement (advanced a charged double-jacketed hand line for 22.9 m). Crawled for 15.2 m and pulled the hose for 15.2 m. 5. Victim rescue (lifted and dragged a 74.8 kg dummy for 22.9 m) 6. Pike Pole (simulated pulling ceilings 7. Equipment Carry (walked 25.9 m with a 10.9 kg chainsaw, then another 25.9 m with a 21.1 kg smoke ejector) Firefighters walked a total of 123.4 m between events.	31.7 ± 8.5	not informed	170 ± 9 (mean)	41.7 *	11.9 ± 1.5	7/11
Bilzon et al. 2001 34 male and 15 female Royal Navy personnel	Two simulated demanding Royal Navy firefighting tasks while wearing PPE and SCBA: 1. Descended a 2.8 m ladder while carrying a 10 kg hose under the arm. They dropped the hose, walked a distance of 14 m and ascended a 2 m ladder back to starting point. Cycle was repeated six times 2. Supported a 10 kg hose with the right hand and opened the nozzle to spray a wall in a "figure-of-eight" motion. Hose was on for 20 s then off for 10 s. Cycle was repeated eight times.	26 ± 6.9 (males) 26 ± 5.8 (females)	1. 240 2. 240	1. Males: Not informed 2. Males: 149 ± 23 1. Females: 166–176 2. Females: 166–176 (mean during last minute of tasks)	1. Males: 39 ± 5 2. Males: 23 ± 6 1. Females: 34 ± 5 2. Females: 24 ± 6	1. Males: 11.1 * 2. Males: 6.6 * 1. Females: 9.7 * 2. Females 6.9 *	9/11

Table 1. *Cont.*

Author Population	Firefighting Tasks	Age (Years)	Time Duration (s)	Heart Rate (bpm)	Mean RVO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$)	Mean METS	CASP Score
Burdon et al. 2019 11 male and 1 female Royal Australian Navy personnel	Three simulations: 1. Firefighting (teams of two): Walked 45 m, descended a 2.7 m ladder, and performed gas cooling for 8 min while holding a 4.5 kg nozzle close to the body. 2. Toxic Hazard 1 (teams of three): Descended two ladders, walked 22.5 m and placed an emergency lift support on a 70 kg dummy. They then ascended a ladder and pulled the dummy with lifting support. 3. Toxic Hazard 2 (teams of two): Walked 22.5 m. One dragged a 70 kg dummy for 15 m and assisted with the fire hose lift. Both firefighters performed a lift and carry with the 70 kg dummy.	26.4 ± 6.2	1. 769 2. 418 3. 485	1. 126 ± 16 (mean) 147 ± 18 (peak) 2. 131 ± 15 (mean) 163 ± 16 (peak) 3. 134 ± 17 (mean) 174 ± 11 (peak)	1. 16.6 ± 3.0 2. 18.4 ± 2.9 3. 20.2 ± 3.7	1. 4.7 * 2. 5.3 * 3. 5.8 *	8/11
Bycura et al. 2019 20 male firefighters	Modified CPAT ** 1. Stair Climb: Firefighters walked up and down a stairwell for 3 min at a pace of 60 steps per min while carrying a 11.3 kg hose over right shoulder. 2. Hose Drag: Replicated CPAT event. 3. Equipment Carry: Used two 11.3 kg weight places to simulate saws. 4. Ladder Raise and Extension: Replicated CPAT event. 5. Forcible Entry: Firefighters struck a car quarter panel 10 times using a 4.5 kg sledge hammer. 6. Search: Replicated CPAT event through a darkened burn room. 7. Rescue: Replicated CPAT event with 77.1 kg hose. 8. Ceiling Breach and Pull: Firefighters raised a 20.4 kg Olympic barbell simulating the pike pole overhead 3 times. They then grasped the rope of a fixed 0.6 m extension ladder as high up and down 5 times. Sequence was repeated 4 times.	44.1 ± 6.4	900	157 ± 2 (mean)	25.2	7.2 *	8/11

Table 1. *Cont.*

Author Population	Firefighting Tasks	Age (Years)	Time Duration (s)	Heart Rate (bpm)	Mean RVO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$)	Mean METS	CASP Score
Dreger & Petersen 2007 30 male and 23 female firefighters	Firefighters had to complete a simulated firefighter work circuit as fast as possible. 1. Hose Carry: 16.5 kg hose for 15.24 m. 2. Ladder Carry and Raise: 13.6 kg ladder for 15.24 m. 3. Hose Drag: With nozzle on shoulder, they walked 30.48 m. 4. Ladder Climb 1: Climbed up and down (3.45 m) 3 times. 5. Rope Pull: Pulled a 16 mm static nylon rope attached to a bundle of hose. 6. Forcible Entry: Hammered a rubber truck tire filled with sand bags with a 4.5 kg sledge hammer. 7. Victim Rescue: Dragged a 68.2 kg mannequin for 30.48 m. 8. Ladder Climb 2: Climbed up and down (3.45 m) 3 times. 9. Ladder Lower and Carry: Lowered a 3.6 m aluminum roof ladder (13.6 kg) and carried it for 15.24 m. 10. Spreader Tool Carry: Picked and carried a 36.4 spreader tool for 15.24 m.	29.0 ± 6.8 (males) 25.8± 5.6 (females)	Males: 365.2 ± 56.3 Females: 442.3 ± 50.8	Males: 168 ± 10 (mean) Females: 171 ± 12 (mean)	Males: 42.4 ± 4.4 Females: 34.8 ± 4.0	Males: 12.1 * Females: 9.9 *	9/11

Table 1. *Cont.*

Author Population	Firefighting Tasks	Age (Years)	Time Duration (s)	Heart Rate (bpm)	Mean RVO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$)	Mean METS	CASP Score
Elsner & Kolkhorst 2008 20 male active firefighters	Firefighters had to complete a simulated firefighter work circuit as fast as possible. 1. Moved a 41 kg hose for 35 m and connected to a hydrant. 2. Carried a 33 kg ladder for approximately 30 m and raised it to a window. 3. Donned their SCBA without putting regulator in mouth. 4. Advanced two sections of a fire hose (82 kg) for 20 m. 5. Hammered a 75 kg wood block with a 4.5 kg sledgehammer. 6. Climbed three flights of stairs. 7. Pulled the two sections of the fire hose (82 kg) with a rope from ground to third floor. 8. Advanced a fire hose through a cluttered area for 30 m. 9. Returned to ground level while shoulder loading a fire hose pack (23 kg). 10. Located a 75 kg mannequin and dragged it for 30 m.	37.4 ± 8.5	699 ± 132	175 ± 7 (mean)	29.1 ± 8.0	8.3 ± 2.2	8/11
Ensari et al. 2017 20 male and 1 female firefighters	Firefighters performed four tasks inside an environmental chamber (temperature 47 °C and humidity 30%). All tasks were performed for two minutes with two minutes of rest in between. 1. Stair Climb. 2. Hose Advance. 3. Search. 4. Overhaul.	29 ± 8.2	1. 120 2. 120 3. 120 4. 120	Approximate values 1. 162 2. 175 3. 178 4. 182 (mean)	1. 37.5 2. 34.2 3. 37.8 4. 31.4	1. 10.7 * 2. 9.8 * 3. 10.8 * 4. 8.9 *	9/11

Table 1. *Cont.*

Author Population	Firefighting Tasks	Age (Years)	Time Duration (s)	Heart Rate (bpm)	Mean RVO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$)	Mean METS	CASP Score
Holmér & Gavhed 2007 15 male professional firefighters	Typical firefighting tasks were completed as fast as possible. 1. Walked/ran on flat ground. 2. Climbed three flights of stairs in a tower and descended four flights. 3. Walked/ran to and crawled through a narrow passage. 4. Walked/ran to and through a house in ruins with two shields at each side. 5. Walked/ran to a house and went up and down three flights of stairs. 6. Repeated 3, 4, and 1.	34.9 ± 8.3	1337 ± 205	168 ± 11 (mean)	33.9	9.7 *	8/11
Kesler et al. 2017 29 male firefighters and 1 female firefighter	Firefighting activities performed in an environmental chamber (temperature 47 °C and humidity 30%). All tasks performed for two minutes. Three different variations with same activities (a. Stair Climb; b. Hose Advance; c. Search; d. Overhaul). 1. 2 min rest between tasks. 2. 2 min rest between tasks and executed each task twice with 5 min rest outside chamber before the second bout. 3. 2 min rest between tasks and executed each task twice.	30.4 ± 1.5	1. 1140 2. 2280 3. 2100	Results from a single-bout 30 min cylinder SCBA a. 163 ± 2 b. 176 ± 2 c. 177 ± 2 d. 180 ± 2 (peak)	Results from a single-bout 30 min cylinder SCBA (RVO_2 peak) a = 28.4 ± 0.9 b = 24.9 ± 0.7 c = 25.0 ± 0.8 d = 19.8 ± 0.7	Results from a single-bout 30 min cylinder SCBA (RVO_2 peak) a = 8.1 * b = 7.1 * c = 7.1 * d = 5.7 *	9/11

Table 1. *Cont.*

Author Population	Firefighting Tasks	Age (Years)	Time Duration (s)	Heart Rate (bpm)	Mean RVO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$)	Mean METS	CASP Score
Mamen et al. 2013 20 male professional firefighters and 1 senior officer	Firefighters performed the 10 events of the Canadian Test (Dreger & Petersen 2007) as fast as possible. They were not allowed to run.	38 ± 7	327 ± 26	174 ± 12 (peak)	Approximately 40	Approximately 11.4 *	8/11
Mamen et. al. 2021 33 male professional firefighters	Firefighters performed the Fredrikstad Test, a modified version of the Canadian Test (Dreger & Petersen 2007, Mamen et al. 2013). An additional hose drag was added after "ladder climb 2" and "ladder climb 3" was added after the "ladder lower and carry". A total of 12 tasks were completed.	37 ± 7	596 ± 66	179 ± 11 (peak)	Approximately 40	Approximately 11.4 *	8/11
Perroni et al. 2010 20 male professional firefighters	Firefighters completed a total of four tasks: 1. Child Rescue: Climbed a firemen's ladder and descended a 3-floor building carrying a 20 kg child dummy. 2. 250 m Run 1. 3. Find an Exit: Completed a maze in a dark chamber. 4. 250 m Run 2.	32 ± 6	1. 81.8 ± 25.3 2. 92.8 ± 24.6 3. 437.5 ± 116.6 4. 91.5 ± 23.7	1. 145 ± 21 2. 166 ± 9 3. 165 ± 10 4. 170 ± 14 (mean)	1. 29.4 ± 6.8 2. 38.5 ± 6.5 3. 28.2 ± 6.8 4. 34.9 ± 7.1	1. 8.4 * 2. 11.0 * 3. 8.1 * 4. 9.9 *	8/11
Säynäjäkangas et al. 2024 34 male and 3 female firefighters	Firefighters completed an updated version of the Finish smoke-diving drill that comprised 5 tasks: 1. Walking without and with two rolls of hose. 2. Stair climbing: Ascended and descended stairs until a total vertical ascent of 20 m was reached. 3. Hammering a truck tire: Performed this task until the truck tire had moved 3 m. 4. Hose pull: Pulled the hose through obstacles. Task was performed twice. 5. Hose rolling.	36.1 ± 9.0	1. 158.9 ± 17.1 2. 152.4 ± 15.2 3. 49.2 ± 26.4 4. 159.6 ± 43.3 5. 70.4 ± 13.2	1. 117 ± 12 2. 137 ± 12 3. 153 ± 14 4. 164 ± 10 5. 157 ± 13 (mean)	1. 20.8 ± 2.8 2. 28.9 ± 2.4 3. 25.1 ± 2.0 4. 35.2 ± 4.6 5. 26.6 ± 3.7	1. 5.9 * 2. 8.3 * 3. 7.2 * 4. 10.1 * 5. 7.6 *	9/11

Table 1. *Cont.*

Author Population	Firefighting Tasks	Age (Years)	Time Duration (s)	Heart Rate (bpm)	Mean RVO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$)	Mean METS	CASP Score
Siddall et al. 2016 50 male and 12 female operational firefighters	Firefighters completed a total of five tasks: 1. Hose Run: Took turns carrying four 13 kg hoses from fire engine to hydrant for a total distance of 700 m. 2. Equipment Carry: Carried a 25 kg barbell eight times on a 25 m course. 3. Stair Climb: The ascended six floors while carrying a 50 kg high-rise pack, descended, swapped the high-rise pack for a 25 kg dumbbell and repeated the task. 4. Casualty Evacuation: Took turns carrying/dragging assorted items (37 kg hose reel, 4 kg sledgehammer, and a 55 kg dummy) in a 25 m square course for about 2.5 min 5. Wild-land Fire: Advanced in an undulating grassy terrain while using a standard 5 kg fire beater. They went uphill (50 m) and downhill two times while equipped with the fire beater and two times without (total = 400 m).	40 ± 10 (males) 37 ± 7 (females)	1. 305 2. 131 3. 364 4. 150 5. 412	Peak steady state of males and females combined 1. 171 ± 11 2. 141 ± 16 3. 166 ± 13 4. 159 ± 13 5. 137 ± 14 (mean)	Peak steady state of males and females combined 1. 47 ± 8 2. 29 ± 5 3. 42 ± 7 4. 36 ± 6 5. 29 ± 5	Peak steady state of males and females combined 1. 13.4 * 2. 8.3 * 3. 12.0 * 4. 10.3 * 5. 8.3 *	9/11
Sothmann et al. 1991 10 male firefighters	Firefighters completed a total of seven tasks: 1. Climbed four flights of stairs while holding a standard fire-axe. 2. Entered a 54 °C room filled with non-toxic smoke and searched for dummy. 3. Removed a 68 kg dummy from the room and dragged it 15 m down a hallway. 4. Re-entered the smoke room and performed 20 pulls on a simulated pike pole. 5. Walked down three flights of stairs, picked a 23 kg hand pump and carried back the upstairs. 6. Re-entered the smoke room and chopped through a 10×10 cm block of wood. 7. Performed 20 more pulls on the simulated pike pole.	31 ± 8	495 ± 143	176 ± 10	31.0 ± 7.0	8.9 *	7/11

Table 1. *Cont.*

Author Population	Firefighting Tasks	Age (Years)	Time Duration (s)	Heart Rate (bpm)	Mean RVO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$)	Mean METS	CASP Score
Tofari et al. 2013 10 male Army emergency responders and 3 non-career firefighters	Participants executed a total of 4 tasks: 1. Fire Suppression: Operated a 51 mm charged fire hose and extinguished the fire of three vehicles. 2. Urban Search and Rescue: Entered a building with a 38 mm charged fire hose, searched and evacuated a 30 kg child dummy and a 70 kg adult dummy. Task was executed inside a dark and smoky hot-fire cell environment heated to 70 °C. 3. Stair Climbing Carrying Equipment: Ascended four flights of stairs while carrying a 36 kg pump ventilator. Walked 28.5, dropped the ventilator and descended four flight of stairs. Repeated task while carrying either two 13.6 kg rolled hoses or one rolled hose and one 7.6 kg Halligan tool. 4. Using Cutting Tools. Performed a casualty (75.3 kg dummy) extraction from a simulated vehicle accident. Quick-cut saw (11.5 kg) and cutters (11.7 kg) were used for 5 min.	28.4 ± 6.4	1. 638 2. 1212 3. 544 4. 300	1. 155 ± 12 (mean) 170 ± 17 (peak) 2. 130 ± 10 (mean) 153 ± 13 (peak) 3. Not informed 4. Not informed	1. 23.2 ± 3.3 2. 26.4 ± 1.4 3. 25.9 ± 0.7 4. 16.9 ± 5.5	1. 6.6 * 2. 7.6 * 3. 7.4 * 4. 4.8 *	8/11
Von Heimburg et al. 2007 14 male part-time firefighters	1. Firefighters climbed six floors. 2. Rescued six simulated patients (total weight 80 kg each) into a safety zone on the same floor. In addition to their firefighting ensemble, they carried a 10 m fire hose, an axe, and a flashlight. Were subdivided into Faster (n = 8) and Slower (n = 6) groups.	38 ± 9	1. 90 ± 31 2. 296 ± 60	1. 167 ± 13 2. 182 ± 15 (peak)	1. 34 ± 4 2. 44 ± 5	1. 9.7 * 2. 12.6 *	9/11

Table 1. *Cont.*

Author Population	Firefighting Tasks	Age (Years)	Time Duration (s)	Heart Rate (bpm)	Mean RVO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$)	Mean METS	CASP Score
Von Heimburg and Medbo 2013 21 male professional firefighters	Firefighters executed three main tasks: 1. Emergency: Performed seven tasks to reach the "scene of fire". Tasks included solving a puzzle, balancing on a 2.5 m wide beam, carrying and dragging a 32 kg fire hose for 58 m, connecting and disconnecting the fire hose, carrying four 23 kg cans for 11 m, and crawling through a 2 m tunnel. Lastly, they walked 58 m to heat chamber. 2. Heat Chamber: Carried ten 18 kg concrete blocks for a total distance of 210 m inside a heat chamber kept at 120–140 °C. 3. Retreat: Performed the same tasks performed during "Emergency" in a reverse order. Total distance walked was 582 m.	42 ± 9	720 ± 180	170 ± 10 (mean)	35 ± 7	10.0 *	7/11
Williams-Bell et al. 2009 33 male and 3 female firefighters	Firefighters performed two tasks: 1. High-rise Stair Climb: Ascended flights of stairs while carrying an 18 kg high-rise pack. Upon achieving 55% of air consumption, they dropped the high-rise pack and descended the stairs toward the exit. 2. Search and Rescue: Ascended five stories while carrying an 18-kg high-rise pack. Dropped the high-rise pack and crawled for 18.3 m. Used a sledge hammer to hit a forcible entry simulator. Entered a room and carried a 75 kg mannequin for 23 m. Descended five stories and reached a safe exit.	40.7 ± 6.6	1. 622 2. 327	1. 166 * 2. 160 ± 13 (mean)	1. 38.3 2. 34.1	1. 10.9 * 2. 9.7 *	9/11

Table 1. *Cont.*

Author Population	Firefighting Tasks	Age (Years)	Time Duration (s)	Heart Rate (bpm)	Mean RVO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$)	Mean METS	CASP Score
Williams-Bell et al. 2010 33 male and 3 female firefighters	Firefighters performed a total of seven tasks in a simulated subway scenario: 1. 1-Floor Descent: Descended one story while carrying a 22 kg high-rise pack over shoulder. 2. Approach Walk: Walked 284 m into the station. 3. Ladder Setup: Dropped the 22 kg high-rise pack and attached a ladder to mount a subway car. 4. Car Search: Searched for a victim through two subway cars (55 m). 5. Guide-Rescue: Rescued a 75 kg mannequin for 27.5 m. 6. Retreat-Walk: Descended the subway car and walked 284 m back to initial stairwell. 7. 1-Floor Ascent: Ascended one story to exit the scene.	41.5 ± 6.5 (males) 31.7 ± 1.5 (females)	730 ± 70	138 ± 17 (mean)	24.3 ± 4.5	6.9 *	7/11

* Variable not reported in the study. It was calculated by the authors based on information provided in the text. ** Values were adjusted to match the International System of Units (SI). SCBA = self-contained breathing apparatus; PPE = personal protective equipment; CPAT = candidate physical ability test.

2.1. Occupational Tasks

All studies included simulated occupational tasks to assess firefighting performance. Tasks executed by firefighters included forcible entry, equipment and hose carry/drag, victim drag/rescue, ladder raise, ladder/stair climbing, and fire suppression. The most common task executed by the firefighters was hose carry/drag (16 studies). Firefighters performed one or more tasks in an environmental/heat chamber with extreme heat conditions in five studies [16,18,23–25].

2.2. Time Duration

Only one study did not report the time duration of the tasks [26]. Overall time to completion was reported in nine studies [6,18,25,27–32] and ranged from 327 [30] to 1337 [29] seconds. Time to complete individual tasks was reported in 10 studies [16,23,24,33–39] and varied based on the distance covered and complexity of the scenario. In general, individual tasks ranged from approximately 49.2 [39] to 769 [34] seconds. Only one study differentiated time to completion for males and females [28].

2.3. Oxygen Uptake (VO_2)

Only one study did not report an RVO_2 value [26]. The RVO_2 value for the respective study was calculated from the firefighters' body mass and absolute rate of oxygen uptake (AVO_2). A total of five studies reported AVO_2 values [24,26,29,34,37]. The AVO_2 values for the remaining studies were calculated from the firefighters' body mass and RVO_2. The overall VO_2 values to complete all tasks was listed for 10 studies [6,18,25–32]. The RVO_2 and AVO_2 values ranged from 24.3 $mL \cdot kg^{-1} \cdot min^{-1}$ [32] and 2.1 $L \cdot min^{-1}$ [32] to 42.4 $mL \cdot kg^{-1} \cdot min^{-1}$ [28] and 4.4 $L \cdot min^{-1}$ [28], respectively. Task-specific VO_2 values were reported for 10 studies [16,23,24,33–39]. Specific RVO_2 and AVO_2 values ranged from 16.6 $mL \cdot kg^{-1} \cdot min^{-1}$ [34] and 1.5 $L \cdot min^{-1}$ [34] to 47 $mL \cdot kg^{-1} \cdot min^{-1}$ [36] and 3.8 $L \cdot min^{-1}$ [36], respectively. Three studies differentiated VO_2 values between males and females [28,33,36].

2.4. Metabolic Equivalents (METS)

Only two studies reported values for METS [6,26]. The METS for the remaining studies were calculated based on firefighters' RVO_2. Overall METS ranged from 6.9 [32] to 12.1 [28] and individual tasks' METS ranged from 4.7 [34] to 13.4 [36]. Three studies differentiated METS values between males and females [28,33,36].

3. Discussion

This review collected, appraised and summarized the available information related to the metabolic and energetic demands of commonly performed firefighting tasks executed in FFE. With few exceptions, the reviewed studies showed a lack of standardization regarding task selection and duration of assessments during circuits. However, this can be explained by the fact that each department may perform tasks that are critical for its surroundings and those vary based on geographical location and population density. As such, the mean metabolic cost of performing a series of tasks varied across studies. The metabolic cost of individual tasks [or a combination of a few individual tasks] also varied based on task characteristics (i.e., weight and number of rescued victims, number of floors to ascend, etc.). As expected, similar tasks that lasted longer or required more individual effort for completion augmented metabolic demands. Overall, the compiled information from the studies included in the review will be an essential resource for fire departments and practitioners working with this population.

3.1. Average Metabolic Demand of Firefighting Tasks

From the 10 studies that reported mean values for the variables of interest, three performed the Canadian Field Test [28,30,31]. The Canadian Field Test is a simulated firefighting work circuit that comprises a series of 10 tasks such as charged hose dragging, forcible entry, victim rescue, and ladder climbing, each separated by the predetermined distances of 15.24 or 30.46 m [28]. In two studies, firefighters performed the original test [28,31], while firefighters in one study completed an extended version of the Canadian Field Test (Fredrikstad Test) with two additional ladder climbs added to the test [30]. Time to completion during the Canadian Field Test was approximately 6 min in both studies, whereas firefighters took about 10 min to complete the Fredrikstad Test. Interestingly, in all three studies, firefighters sustained an average of approximately 40 $mL \cdot kg^{-1} \cdot min^{-1}$ or 11.4 METS for about 70% of the total time. Although Adams et al. [26] did not report the overall time duration of the circuit test, they also reported a similar mean RVO_2 (41 $mL \cdot kg^{-1} \cdot min^{-1}$ or 11 METS). These results are close to the minimum aerobic capacity recommended by the NFPA 1582 [11]. It should be noted that this value is typically obtained through a standardized treadmill test and represents peak RVO_2 in athletic attire. However, during these circuits, the firefighters performed tasks in FFE, which naturally reduces RVO_2 capacity [22], and had to sustain this RVO_2 for several minutes. For these reasons, it is plausible to consider that depending on age-adjusted values, some firefighters had to perform tasks at near-maximal or even supramaximal levels. This highlights the importance of prioritizing the ability to maintain a sufficient level of RVO_2 during prolonged fieldwork.

On the other hand, the other six studies that reported the metabolic demand of a series of firefighting tasks reached lower values ranging from 24.3 $mL \cdot kg^{-1} \cdot min^{-1}$ (6.9 METS) [32] to 35 $mL \cdot kg^{-1} \cdot min^{-1}$ (10 METS) [25]. However, interpretation of such results must be made with caution. For instance, Elsner et al. [6] and Sothmann et al. [18] reported mean RVO_2 values of 29.1 $mL \cdot kg^{-1} \cdot min^{-1}$ and 31.0 $mL \cdot kg^{-1} \cdot min^{-1}$, respectively, upon completion of firefighting circuit tasks. Even though mean RVO_2 values were approximately 20% lower than their RVO_{2max}, the mean HR of firefighters in both studies was approximately 95% of their age-predicted maximal HR and equivalent to the HR achieved during their treadmill RVO_{2max} tests [6,18]. In these cases, there may be a possible inconsistency in relative metabolic demand to complete the circuit tasks. This inconsistency may be attributed to the fact that firefighters performed RVO_{2max} tests without their FFE. Considering firefighters tend to reach an RVO_{2max} approximately 20% higher when wearing athletic clothes [20–22], it seems plausible to consider that firefighters may have reached a mean RVO_2 compatible with the guidelines. However, further research is required to confirm this supposition.

The effects of fatigue on the metabolic demand of performing these tasks were also present in several studies. In two of the studies, time to complete the tasks was over 20 min [23,29]. In one study, firefighters performed a series of tasks that involved walking, running and crawling through typical firefighting scenarios [29]. The authors reported test means for HR and RVO_2 of 168 bpm (beats per minute) and 33.9 $mL \cdot kg^{-1} \cdot min^{-1}$, respectively. However, in the second half of the circuit (~10 min), which included the repetition of some of the tasks already performed, minute ventilation increased by approximately 20%. It remained high until the test's conclusion, and HR reached values as high as 200 bpm. Similarly, in another study firefighters reached higher minute ventilation and HR values following repetition of a sequence that involved stair climbing, hose advance, search, and overhaul one additional time, even when controlling for execution time and rest periods [23]. Due to accrued fatigue, there was a significant increase in core temperatures and a reduction of approximately 20% in total work and, as a consequence, peak RVO_2. Additionally, the physiological strain on the firefighters may persist for over 30 min following sustained effort. For instance, Säynäjäkangas et al. [39] monitored the physiological

recovery of the firefighters who completed five sequential tasks in approximately 15 min. After 10 min, the firefighters' VO_2, ventilatory exchange, and respiratory exchange ratio remained elevated compared to baseline, and even after 30 min, their heart rate and lactate concentration were still higher than baseline. These results bring light to the importance of ecological validity of testing procedures with this population. When assessing the metabolic demand and/or operational capacity of firefighters, the metabolic effects of accrued fatigue need to be accounted for. Furthermore, the persistence of physiological strain underscores the need for adequate recovery periods between tasks to ensure operational safety and mitigate the risk of potential long-term health consequences.

Although presenting the mean RVO_2 of a circuit task provides an overall idea of the metabolic demand of firefighting, it may not be the best approach. Oxygen uptake tends to fluctuate across the tests and it is largely affected by accrued fatigue. As a consequence of performing firefighting tasks for extended periods of time, there will be an increase in core temperature that will lead to a decline in RVO_2 and total work performed [23,40]. In addition, minute ventilation tends to increase which may affect the firefighters' ability to manage the oxygen in their SCBA. The complexity and versatility of the firefighter occupation require analyses of individual tasks performed while equipped with a complete FFE for a better understanding of their metabolic demands.

3.2. Metabolic Demand of Individual Firefighting Tasks

Individual tasks commonly executed in firefighting scenarios included variations of ladder deployment, stair and ladder climbing, hose and equipment dragging, gas cooling, search and overhaul, and victim rescue. The RVO_2 required to complete individual tasks ranged from with 16.6 to 47 $mL \cdot kg^{-1} \cdot min^{-1}$. The least demanding activity required an RVO_2 of 16.6 $mL \cdot kg^{-1} \cdot min^{-1}$ or 4.7 METS (performing gas cooling of a building for eight minutes) [34], and the most demanding activity required an RVO_2 of 47 $mL \cdot kg^{-1} \cdot min^{-1}$ or 13.4 METS [jogging while unreeling 13 kg fire hoses multiple times] [36].

3.2.1. Stair/Ladder Climbing

Ladders and stairs are often used in firefighting and an important way to reach upper floors or other high areas where victims may be trapped or where fires may be burning. The metabolic cost of stair/ladder climbing in each study varied according to the duration of the task, external load being transported, and number of floors being covered. The least demanding task involving ladder climbing was reported by Burdon et al. [34] (RVO_2 of 16.6 $mL \cdot kg^{-1} \cdot min^{-1}$ or 4.7 METS). It should be noted that in this task, firefighters acted in groups of two and performed gas cooling for approximately eight minutes [34]. Since the mean RVO_2 was reported, it is difficult to quantify the demand of the ladder climbing alone. In the same study [34], firefighters descended and ascended two ladders while rescuing a 70 kg dummy with an emergency lifting support. Once again, they acted in teams of three firefighters, which makes it difficult to quantify their individual metabolic demand. Nonetheless, this approach resembled what is commonly done in the field, which added ecological validity to the assessment. This is also important because working in small teams can redistribute the workload, which will prevent firefighters from becoming overly fatigued and maintain operational safety.

Higher metabolic demands were found in studies where firefighters continuously worked alone. In three studies, firefighters ascended stairs without carrying additional external load [16,23,37]. In two studies, firefighters followed the same protocol in a laboratory setting [16,23]. Firefighters in these investigations executed simulated star climbing for two minutes under the same conditions (inside an environmental chamber at 47 °C and 30% humidity) and were instructed to maintain a pace compatible with a real-life

situation. However, the metabolic demands differed slightly. While Kesler et al. [23] found a peak RVO_2 of 28.4 $mL \cdot kg^{-1} \cdot min^{-1}$ (8.1 METS), Ensari et al. [16] reported a mean RVO_2 of 37.5 $mL \cdot kg^{-1} \cdot min^{-1}$ (10.7 METS). There may be two factors accounting for this discrepancy. First, the mean RVO_{2max} values of the participants were different, indicating a contrast in firefighters' fitness levels across studies. Kesler et al.'s [23] and Ensari et al.'s [16] participants portrayed RVO_{2max} values of 43.7 $mL \cdot kg^{-1} \cdot min^{-1}$ and 50.1 $mL \cdot kg^{-1}$, respectively. Second, Kesler et al. reported a discrete value for RVO_2 (RVO_2 peak), whereas the results presented by Ensari et al. [16] are the means for the last minute of the test (50% of the test). For these reasons, it seems plausible to consider the results reported by Ensari et al. [16], a better indication of the average metabolic cost of ladder climbing while in FFE.

This affirmation is supported by the results presented by Von Heimburg et al. [41]. In their study, firefighters achieved an RVO_2 of 34 $mL \cdot kg^{-1} \cdot min^{-1}$ (9.7 METS) after climbing six floors in approximately 1.5 min in a simulated real scenario. In relative terms, just by ascending flights of stairs for about one minute, firefighters from both studies reached approximately 70% of their RVO_{2max}. However, lower values may be reached when there is a combination of ascent and descent during this task. For instance, one study had the firefighters ascending and descending stairs for approximately 3 min until a vertical ascent of 20 m was achieved [39]. The RVO_2 for this task was 28.9 $mL \cdot kg^{-1} \cdot min^{-1}$ (8.5 METS), which corresponded to approximately 59% of their RVO_{2max}. In this scenario, the firefighters were instructed to complete the tasks as they would in a real-life situation, allowing them to pace themselves throughout. The lower metabolic demand observed in this study, when compared to others, may be attributed to the descent portion of the task acting as an active rest, reducing the overall metabolic demand compared to a continuous ascent. These findings demonstrate that even slight variations in task scenarios can significantly influence the physiological workload. This underscores the importance of pacing strategies to effectively manage metabolic demands.

Carrying equipment while ascending stairs may increase the metabolic demand because of the additional weight firefighters must lift and move. However, despite the increase in relative load, the RVO_2 values remained similar to the aforementioned studies. For instance, in two studies firefighters had to ascend and descend floors while carrying an external load [24,35]. In one study, firefighters climbed a ladder for a height equivalent to three floors and descended three flights of stairs while carrying a 20 kg dummy [35]. The mean RVO_2 required to execute this task was 29.4 $mL \cdot kg^{-1} \cdot min^{-1}$ (8.4 METS) [35]. In the second study, firefighters ascended four flights of stairs while carrying a 36 kg ventilator, dropped it, and descended the stairs [24]. They repeated the task while carrying two rolled hoses weighing 13.6 kg each. The mean RVO_2 required to execute this task was 25.9 $mL \cdot kg^{-1} \cdot min^{-1}$ (7.4 METS) [24]. It seems that adding external weight to stair climbing while in FFE has little effect on the overall metabolic demand.

However, there is an increase in the metabolic demand when performing ladder and stair climbing continuously with external load. For instance, Williams-Bell et al. [38] reported a mean RVO_2 value of 38.3 $mL \cdot kg^{-1} \cdot min^{-1}$ (10.5 METS) in firefighters who uninterruptedly ascended stairs for approximately 10 min while carrying an 18 kg high-rise pack. In another study, firefighters reached mean RVO_2 values of 39 $mL \cdot kg^{-1} \cdot min^{-1}$ (11.1 METS) and 34 $mL \cdot kg^{-1} \cdot min^{-1}$ (9.7 METS), for males and females, respectively, while repeating a circuit that involved ascending and descending ladders while carrying a charged hose for four minutes [33]. Similarly, Siddall et al. [36] reported RVO_2 values of 41 $mL \cdot kg^{-1} \cdot min^{-1}$ (11.7 METS) and 40 $mL \cdot kg^{-1} \cdot min^{-1}$ (11.4 METS), for males and females, respectively, following the ascending and descending of six floors with external load twice in six minutes. It should be noted that although these values are very high, they do not

represent the mean of the entire task but the mean RVO_2 of the last minute of the task (peak steady state) [36].

Overall, the increase in the metabolic demand and RVO_2 values seems to be the consequence of energy expenditure while performing the same activity continuously with extra external load. The added weight of the external load increases the amount of force that muscles must generate to carry on with the task, which increases the amount of oxygen consumed [41]. While executing similar scenarios, these discrepant results highlight the importance of firefighters pacing themselves and coordinating their efforts as a team to reduce metabolic stress, especially when the emergency demands continuous locomotion through ladders or flights of stairs while carrying external loads.

3.2.2. Victim Drag/Rescue

A victim drag is a technique used by firefighters to rescue a person from a dangerous or inaccessible location. Ideally, firefighters will secure the victim in a harness or blanket and then use a rope or something similar to pull them to safety. The victim drag is important because it allows firefighters to efficiently remove victims from harm's way, reducing the risk of injury or death. The metabolic cost of victim drag/rescue also varied among studies based on execution time and body mass of the simulated victims. Values for this task ranged from 20.2 $mL \cdot kg^{-1} \cdot min^{-1}$ (5.7 METS) [34] to 44 $mL \cdot kg^{-1} \cdot min^{-1}$ (12.6 METS) [37]. Burdon et al. [34] reported a mean RVO_2 of 20.2 $mL \cdot kg^{-1} \cdot min^{-1}$ (5.8 METS) in one of the drills of their study. However, firefighters were working in teams of two while carrying a 70 kg dummy for 15 m and assisting with a fire hose lift. The entire task lasted for approximately eight minutes, which may have influenced the final mean RVO_2. As aforementioned, by working as a team, firefighters can share the job's physical demands, reducing the workload during sustained physical efforts. This assumption helps to explain the low mean RVO_2 value in this study and highlights the importance of teamwork during physically demanding firefighting tasks. Nonetheless, the peak reported for this task was an RVO_2 of 32.6 $mL \cdot kg^{-1} \cdot min^{-1}$ (9.3 METS) [34]. Since the most metabolically demanding action performed by the firefighters in this simulation was the casualty rescue, an approximate mean RVO_2 value of 32.6 $mL \cdot kg^{-1} \cdot min^{-1}$ for this specific task can be assumed.

This assumption is corroborated by Siddall et al. [36] and Williams-Bell et al. [38]. In their studies, firefighters executed similar protocols that started with a forcible entry and ended with a simulated victim evacuation. Siddall et al. [36] found a peak combined (male and female) RVO_2 value of 36 $mL \cdot kg^{-1} \cdot min^{-1}$ (10.3 METS) following the evacuation of a 55 kg dummy for 10 m. Williams-Bell et al. [38] reported a mean RVO_2 value of 34.1 $mL \cdot kg^{-1} \cdot min^{-1}$ (9.7 METS) following the evacuation of a 75 kg dummy for 23 m. As aforementioned, Siddall et al. [36] reported the mean RVO_2 value of the last minute of each task completed. However, since the casualty evacuation was the last action performed, the value reported seems an appropriate indicator of the metabolic demand of this particular task. On the other hand, the firefighters in the study by Williams-Bell et al. [38] descended five floors following the rescue. This may have impacted their overall metabolic demand. Nonetheless, firefighters were engaged in realistic scenarios and the results of these studies show how taxing the rescuing of victims can be to a firefighter, even when performing the task a single time and for short distances. More importantly, these results highlight the importance of not only being able to reach high RVO_2 levels but also the ability to endure through highly demanding tasks.

In fact, two studies have shown that endurance is important for firefighters when performing multiple rescues [24,37]. In one study, Tofari et al. [24] found a mean RVO_2 value of 26.41 $mL \cdot kg^{-1} \cdot min^{-1}$ (7.5 METS) following the execution of an urban search and rescue simulation that included the evacuation of a 70 kg dummy and a 30 kg dummy. Because

the casualty evacuation was part of a search and rescue simulation and the firefighters had to perform other tasks, the mean RVO_2 reported does not seem an accurate indicator of the metabolic stress of this specific task. Nonetheless, the authors reported a peak RVO_2 value of 42.89 $mL \cdot kg^{-1} \cdot min^{-1}$ (12.2 METS) for this task [24]. Since the extractions were the most strenuous tasks reported in this simulation, it seems plausible to assume this value as the appropriate metabolic demand for the task.

This assumption is corroborated by the results reported by Von Heimberg et al. [37]. In their study, firefighters dragged six 80 kg dummies to a safe zone and the mean RVO_2 was 44 $mL \cdot kg^{-1} \cdot min^{-1}$ (12.6 METS). It should be noted that the entire urban search and rescue scenario took about 20 min to be completed by the firefighters and the mean RVO_2 corresponded to about 45% of their VO_{2max} [24]. Undeniably, the metabolic demand of performing victim extractions is one of the highest, and although their duration varies, it is usually short. However, it is important for firefighters to remain alert and focused throughout the emergency situation. From a training perspective, these results show the importance of introducing circuits that include high-intensity and short-duration exercises to their training to simulate the occupational demands of the job [42].

3.2.3. Hose Carry and Fire Suppression

In order to suppress and extinguish a fire, firefighters must carry or drag fire hoses to deliver water to the fire site. Following the deployment of the fire hose, firefighters manage to cool down the surrounding area and prevent the spread of fire by delivering large amounts of water to the fire. While the metabolic demand of carrying a fire hose varied between the studies, more stability was seen in the fire suppression tasks. In two studies, a hose advance simulation was executed for two minutes inside an environmental chamber at 47 °C and 30% humidity [16,23]. Kesler et al. [23] reported an RVO_2 of 24.9 $mL \cdot kg^{-1} \cdot min^{-1}$ (7.1 METS) and Ensari et al. [16] found an RVO_2 of 34.2 $mL \cdot kg^{-1} \cdot min^{-1}$ (9.8 METS). As discussed previously, the probable reasons for the discrepancy between these two studies are related to how the data were presented and the cardiorespiratory fitness level of the participants. Two studies presented individual values for hose carry [36,39].

Säynäjäkangas et al. reported the metabolic demand of a hose pull performed while going under and over obstacles [39]. Firefighters completed the task twice and this was the most taxing activity of the study, with firefighters reaching an RVO_2 of 35.2 $mL \cdot kg^{-1} \cdot min^{-1}$ (10.1 METS). This value accounted for approximately 73% of their RVO_{2max} and 86.8% of their maximal HR. In the same study, the firefighters had to roll the 20 m hose in their hands. They reached an RVO_2 of 26.6 $mL \cdot kg^{-1} \cdot min^{-1}$ (7.6 METS) during this task [39]. In the second study, firefighters had to jog while unraveling four 13 kg hoses (25 m each) [36]. They repeated this task for a total distance of 700 m and the minimum expected time to completion was approximately five minutes. Males and females reached very similar metabolic demands, with a combined RVO_2 47 $mL \cdot kg^{-1} \cdot min^{-1}$ (13.4 METS). Interestingly, the combined RVO_{2max} of this cohort of firefighters was 50 $mL \cdot kg^{-1} \cdot min^{-1}$ and they reached this value while wearing normal athletic clothes [36]. Firefighters achieved an average value of approximately 94% of their RVO_{2max} with some individuals reaching supramaximal levels. As previously mentioned, the metabolic demand increases as a consequence of wearing an FFE [41]. When wearing an FFE, firefighters achieve values approximately 20% lower than their RVO_{2max} even when exercising strenuously [20–22]. Therefore, this task was extremely taxing for the firefighters' cardiorespiratory systems and potentially harmful for unfit individuals.

It should be noted that firefighters performed this task individually, and the physiological strain in a real scenario can be diminished when working as a team. Assuming the

hose deployment is usually the first activity performed on a fire scene, the cardiovascular strain and accrued fatigue may impair one's decision making and cognitive function. In addition, the added load of their FFE and equipment may elevate the metabolic cost of exercise and elevate fatigue levels while decreasing the maximal duration for continuous work [41,43]. By working as a team, firefighters can manage their fatigue levels and perform their subsequent duties at their best.

More stability was found in the metabolic demand of tasks involving fire suppression, which was consistent between studies. Firefighters executing gas cooling for eight minutes portrayed an RVO_2 of 16.6 $mL \cdot kg^{-1} \cdot min^{-1}$ (4.7 METS) [34] and an RVO_2 of 23.2 $mL \cdot kg^{-1} \cdot min^{-1}$ (6.6 METS) while operating a fire hose for 10 min [24]. The metabolic demand was also stable when comparing males and females performing this task. After operating a fire hose for four minutes, males and females portrayed an RVO_2 of approximately 24 $mL \cdot kg^{-1} \cdot min^{-1}$ (6.9 METS) [33]. It should be noted that in a real scenario, fire suppression will be executed following other actions such as hose and ladder deployment and carrying heavy equipment. Although the metabolic demand of fire suppression is relatively low, in some cases it has to be executed repeatedly for several minutes in a challenging environment. In addition, the heat and smoke from fires may affect firefighters' thermoregulation, altering heart and respiratory rate [44]. Since improved thermoregulatory control is associated with higher cardiorespiratory fitness levels [45], firefighters with higher RVO_{2max} may be able to perform fire suppression more effectively while preventing heat-related injuries.

3.2.4. Limitations

There are potential limitations to applying tests with construct validity to assess the physical fitness of firefighters. Overall, there is a lack of standardization in testing procedures, with a few exceptions. Some studies reported mean VO_2 values for the entirety of the task while others reported peak values or mean values of a fraction of the task. A myriad of field tests with varied duration were employed to determine physical preparedness and assess the metabolic demand of firefighting. Another potential limitation is that despite the fact that all firefighters must be fit to execute all tasks, tests may not account for sex differences and body size and composition. The effect of absolute loads on performance should be addressed. Otherwise, the analysis and comparison of test results between individuals will be complicated and may not provide an accurate assessment of their physical capabilities for firefighting. Two individuals may have the same RVO_{2max} but may not be able to perform the same workload due to the effect of absolute load carriage. Additionally, the reliability of tests may also be affected by fatigue. As firefighters work longer shifts, or the load is more taxing on their bodies, their fatigue levels will rise, which can lead to a decreased work capacity [41,43]. Consequently, it is also important to consider appropriate rest and recovery during extended real-life scenarios for fatigue mitigation and optimal firefighting capability.

4. Materials and Methods

4.1. Search Strategy and Information Sources

The systematic literature search was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [46]. Initial terms were determined upon a preliminary review of the literature and refined based on their relevance to answering the study's question. An extensive literature search comprising three academic databases (PubMed, Embase, and SPORTDiscus) was conducted up to 10 October 2024. The selected search terms for each database are summarized in Table 2.

Table 2. Databases and search terms.

Database	Search Terms	Filters	Results (n)
PubMed	(VO_{2max}) OR (oxygen consumption) OR (oxygen uptake) OR (cardiorespiratory fitness) OR (energy cost) OR (carbon dioxide output) AND (Occupational test) OR (task performance) OR (occupation) AND ("firefighter"[Title/Abstract]) OR ("Firefighting"[Title/Abstract]) NOT (cancer) NOT (disease) NOT (review) NOT (meta-analysis)	Sort by best match	1216
Embase	(firefighter:ab,ti OR 'fire fighter':ab,ti OR firefighting:ab,ti OR 'fire service':ab,ti) AND (VO_{2max}:ab,ti OR 'oxygen consumption':ab,ti OR 'oxygen uptake':ab,ti OR 'cardiorespiratory fitness':ab,ti)	Sort by best match	82
SPORTDiscus	(firefighter OR fire fighters OR fire service OR firefighting) AND (cardiorespiratory endurance or cardiorespiratory fitness OR cardiorespiratory function OR maximal oxygen uptake OR VO_{2max} OR maximal oxygen intake OR air consumption)	Search modes SmartText searching	165

4.2. Selection Process

All identified records were collected and duplicates were removed. Records were then subjected to the eligibility criteria. Each record was individually screened by two of the investigators (M.L.d.S. and J.D.) to reduce the potential for selection bias. In case of a disagreement between the two investigators, a third investigator was consulted (T.D.M.). Figure 1 portrays the flow diagram demonstrating the search strategy and selection process.

4.3. Eligibility Criteria

The studies included in this review met all the following inclusion criteria: (a) full texts published in English-language journals; (b) included firefighters; (c) included a direct measure of oxygen uptake (portable metabolic system); (d) included simulated firefighting tasks; (e) assessments were performed while wearing FFE; and (f) allowed the extraction of data for analysis (see Data Extraction). Exclusion criteria included (a) non-human studies; (b) studies not published in English; (c) not original research; and (d) meta-analyses and reviews.

4.4. Data Extraction and Data Items

Two reviewers separately and independently extracted the data to be utilized in this review (M.L.d.S. and J.D.). In case of a disagreement between the two investigators, a third investigator was consulted (T.D.M.). Data were then aligned into a single table. Relevant data included participant characteristics (i.e., height, body mass, age, etc.) and study characteristics (i.e., type of tasks performed, AVO_2, RVO_2, and METS) were extracted. If

the study did not include the value for AVO_2, these were calculated from the firefighters' body mass and RVO_2 values through Equation (1).

$$AVO_2 = \frac{RVO_2 * BM}{1000} \quad (1)$$

If the study did not include the values for METS, these were calculated from the RVO_2 by using conversion (Equation (2)) [47,48].

$$METS = \frac{RVO_2}{3.5} \quad (2)$$

4.5. Risk of Bias Assessment

Methodological quality of the studies was evaluated based on the eleven questions that comprise the Critical Appraisal Skills Programme [CASP] checklist for randomized controlled trials [49]. The possible answers for each question on the CASP checklist are "yes", "can't tell", and "no". One point is given for each "yes" answer and zero points are given to both "can't tell" and "no" answers. Therefore, the maximum score was 11 out of 11 points. Quality of each study was also individually screened by two of the investigators (M.L.d.S. and J.D.) to reduce the potential for bias.

5. Conclusions

Agencies must be aware that the NFPA recommendations for cardiorespiratory fitness levels are based on the peak RVO_{2max} achieved during a treadmill or cycling graded exercise test performed with athletic attire. This review demonstrates that firefighters may work at intensities as high as 40 $mL \cdot kg^{-1} \cdot min^{-1}$ (11.4 METS) for several minutes during simulations while in an FFE. These findings highlight the need for firefighters to develop a higher peak RVO_{2max} to ensure they can perform their duties safely. Without sufficient aerobic capacity, they may be required to sustain near-maximal or even supramaximal effort during extended job tasks, increasing fatigue and the risk of performance decline, injury, and death. Furthermore, when working in the field and depending on the nature of the emergency, firefighters are often exposed to environmentally challenging situations while facing heat stress. Therefore, from an occupational performance standpoint, it seems vital to assess firefighters' occupational readiness by quantifying how long they can sustain continuous effort without significant performance decline, rather than solely focusing on whether they reach the recommended minimum values adjusted by age and sex.

From a training perspective, it is plausible to consider that each fire station will follow general guidelines but would try to faithfully reproduce possible scenarios and load conditions according to their local needs (e.g., including extended stair climbing tasks in cities with a higher prevalence of high-rise buildings). The focus of the training should be on developing sufficient aerobic capacity to handle intermittent high-intensity tasks. For this reason, quantifying the metabolic demand of commonly performed firefighting tasks with varied durations is essential. Moreover, the execution of individual tasks while in FFE may allow for better information on the effect of the absolute load carriage in relative metabolic demand of each firefighter. This information can be later used when prescribing training programs focused on optimizing firefighting. It is suggested to create a tool similar to the Compendium of Physical Activities [47] designed specifically for firefighters. This tool could help quantify both the metabolic cost of specific firefighting tasks and the impact of performing those tasks for varying durations. These data may enable tactical trainers to design and implement simulated scenarios and training programs for firefighters with optimal construct validity.

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