CCI JOURNAL CRITICAL CARE INNOVATIONS

ORIGINAL ARTICLE

Crit. Care Innov. 2023; 6(4): 1-10

ISSN 2545-2533

Received: 25.10.2023
Accepted: 19.11.2023
First online: 20.11.2023
Published: 31.12.2023

The impact of firefighter fatigue on the quality of chest compressions during resuscitation.

Paulina Gryz [1] - A,B,C,F,G,H,K,L,M,N,O. ORCID www.orcid.org/0000-0003-4764-9192
Jakub Kowalski [1] - A,B,C,F,H,I,J,L,M,N,O. ORCID www.orcid.org/0000-0002-1369-1723
Piotr Konrad Leszczyński [1] - B,C,E,F,G,H,K,L,M,N,O. ORCID www.orcid.org/0000-0002-3408-3591
Martyna Miftadinow [1] - J,K,L,N,O. ORCID www.orcid.org/0009-0007-7237-3585
Katarzyna Szubińska [2] - E,K,L,M,N,O. ORCID www.orcid.org/0009-0005-5687-3956

[1] *Faculty of Medical Sciences and Health Sciences, University of Siedlce, Poland.*
[2] *Provincial Headquarters of the State Fire Service in Warsaw, Warsaw, Poland*

Address for correspondence:
Paulina Gryz. *Faculty of Medical Sciences and Health Sciences, University of Siedlce, Konarskiego 2 Str. 08-110 Siedlce, Poland.; e-mail: paulina.gryz@uws.edu.pl; tel: +48 25 643-15-51*

Author Contributions (CRediTTaxonomy):

Conceptualization - **A**
Data Curation - **B**
Formal Analysis - **C**
Funding Acquisition - **D**
Investigation - **E**
Methodology - **F**
Project Administration - **G**
Resources - **H**
Software - **I**
Supervision - **J**
Validation - **K**
Visualization - **L**
Writing (Draft Preparation) - **M**
Writing (Review & Editing) – **N**
Approved the final version - **O**

ABSTRACT

INTRODUCTION: The effectiveness of cardiopulmonary resuscitation depends primarily on the actions taken at the scene. Firefighters are often the first ones to help the injured. The quality of their rescue efforts in such case determines the subsequent prognosis for the patient. Nevertheless, the tasks of firefighters also involve activities associated with a lot of physical activity, which can cause them to lose strength faster during CPR. The aim of the study was to assess the impact of fatigue on the quality of CPR performed by firefighters.

MATERIALS AND METHODS: The study group consisted of 100 firefighters of volunteer firefighting units in the Siedlce poviat in Poland. The study was divided into three stages: I - performing chest compressions in a timed regime, II - subjecting the study group to uniform physical activity, III - reassessing the quality of chest compressions. The effectiveness of CPR was analyzed using a computer system and a professional training model. To analyze the variables, the normality of the distribution was determined using the Shapiro-Wilk test, and then the non-parametric test for uncorrelated variables Mann-Whitney U was used. Correlations were tested using the r-Pearson test at $p<0.05$ significance.

RESULTS: The study group consisted of 93 men and 7 women, with a mean age of M=30.84 (SD ± 10.95). The respondents mostly had secondary education (42%) and vocational education (24%), with the majority (54%) declaring their marital status as single. Firefighters with varying ranks, including commanders, chiefs and presidents, participated in the study. The overall quality of chest compressions was lower each time after physical activity, at each analyzed minute of stage I and stage III (minute 1: 84.56% vs. 81.68%, p=0.281; minute 2: 81.13% vs. 80,25%, p=0,558; minute 3: 81.91% vs. 77.78%; p=0.243). A significantly higher quality of chest compressions was observed among men compared to women, both before fatigue (p=0.019) and after physical activity (p=0.053). Participants in the >53 age group had the best resuscitation scores in both during fatigue (90.78%) and before physical activity (90.83%). There was no significant correlation with rank or function of firefighters. Among the parameters of chest compressions evaluated in the third minute, the greatest effect of fatigue was shown in the aspect of the compression rate (59.42% vs. 49.20%) and depth (71.61% vs. 67.86%).

CONCLUSIONS: Physical fatigue of firefighters results in moderate decrease in the effectiveness of chest compressions, especially in terms of the rate and depth of compressions. The overall quality of chest compressions is significantly higher in men than in women both before and after physical activity. The experience of firefighters can translate into the quality of resuscitation, regardless of their age.

KEY WORDS: Resuscitation, chest compressions, firefighter, fatigue, quality.

INTRODUCTION

Members of Volunteer Fire Departments (VFDs) have top-down tasks, which include fighting fires, eliminating local hazards, as well as a wide range of rescue operations – including water and medical rescue. Firefighters are certified in the field of qualified first aid (QFA). Qualified first aid - according to Article 3 pt. 2 of the Polish Law of September 8, 2006 on State Emergency Medical Services (Dz. U. - Polish Journal of Laws of 2006 No. 191 item 1410) - is defined as "*actions taken towards a person in a state of emergency by a rescuer*" [1]. Firefighters are very often the first ones on the scene, which certainly affects the need to improve their emergency medical skills as a support to the State Fire Service (SFS) and emergency medical service (EMS) teams. During a mass casualty incident or disaster, firefighters have the ability to perform initial medical segregation thanks to additional skills. The most important goal of the QFA training of members is to prepare the participating rescuers for their rescue operations, up to the point of handing over the injured person to the emergency medical team. Only VFD units included in the national rescue and firefighting system can carry out medical rescue tasks at the basic level (i.e. QFA). Firefighter-rescue worker job is characterized by extremely high risk level, so those who choose such a career path should have a high level of mental and physical fitness, as well as high resistance to stress. Situations in which firefighters are very often put, require them to react quickly, a great deal of prudence, a lot of mental toughness and appropriate behavior towards the injured in any situation. Candidates are required not only to be medically fit, but also to have exceptional mental and physical fitness, therefore only people with a balanced psyche, strong physique, and who are fully healthy and fit are admitted to the profession [2]. Fitness of the skeletal, muscular, circulatory and, above all, respiratory systems is also very important when working wearing air breathing apparatuses. It is also important to have a high degree of hearing, vision, touch and smell [3].

Most of the listed characteristics have a major impact on the quality of cardiopulmonary resuscitation (CPR), which can be a key factor in achieving positive clinical outcomes following sudden cardiac arrest (SCA). According to the definition, CPR is "the actions by which breathing (with a palpable pulse) or breathing and circulation are restored in a casualty" [4]. When considering the activities performed in CPR, several factors that affect the quality of CPR can be listed:

- **Depth of chest compressions** – should be 5 - 6 cm; when compressions are too deep, the risk of complications (rib or sternum fractures) increases, while the effectiveness of CPR is reduced when they are too shallow.
- **Chest compression rate** – is 100-120 compressions per minute; there is a risk of reduced survival rates for casualties below this level.
- Place of compressions – the European Resuscitation Council's ILCOR recommendations provide information on teaching compressions at the center of the chest with the position of the hands in the lower half of the sternum.

- **Proper position of the rescuer** – straight arms, not bent at the elbows, positioned perpendicular to the chest.
- **Hard surface when performing CPR** – with a soft surface, both the chest and the surface beneath the casualty (such as a mattress) are compressed, which can lead to a decrease in the actual depth of compressions.
- **Impact of change cycles** – high intrathoracic pressure results in reduced coronary perfusion, while incomplete decompression occurs when complete chest relaxation cannot occur in the moment before the next compression is initiated, which is often seen as an effect of rescuer fatigue.
- **Limiting interruptions** – when performing chest compressions, there is a high risk of distraction, and rescuer fatigue is also an additional factor in prolonging interruptions; the frequency of chest compressions. Microcirculation and coronary vascular perfusion decrease over time, and according to the literature, there is a significant decrease after 2 minutes of CPR, so any interruptions (e.g., for ventilation, rhythm control, or airway clearance) affect the decrease in perfusion and, consequently, the effectiveness of CPR.
- **Effect of ventilation rate** – implementation of an adequate compression-to-ventilation ratio (30:2) is associated with better neurological outcomes in adult patients and higher survival rates than when a ratio (15:2) is used.
- **Psychophysical condition of the rescuer** – fatigue of the rescuer compromises the quality of CPR performed (compressions that are too shallow, or low chest compression rates, prolonged pauses between compressions and rescue breaths, or pauses during the rescuer's shift cycle) [5,7].

There are many factors that improve the quality of CPR, with a significant role played by the rescuer's adequate psychophysical state. Therefore, firefighter's fatigue while performing CPR can compromise the effectiveness of chest compressions.

The purpose of the study was to investigate the effect of firefighter fatigue on performing effective chest compressions before and after significant physical activity of firefighter, and to identify technical problems in the performance of chest compressions under fatigue. Sociodemographic factors were also analyzed by conducting correlations of variables.

MATERIALS AND METHODS

The study was conducted on a sample of 100 firefighters of volunteer firefighting units (VFDs) in the Siedlce district of Poland. The study was divided into three stages:

1. performing chest compressions (visual and computer evaluation of parameters after 1, 2 and 3 minutes),
2. physical activity in the form of running 200 m with an air breathing apparatus in a specific time regime,

3. re-performing chest compressions with visual and computer evaluation of resuscitation parameters after 1, 2 and 3 minutes.

The inclusion criteria were informed consent of the subjects and completion of all stages. The study was approved by the Research Ethics Committee of the University of Siedlce under Resolution No. 28/2022 dated November 16, 2022.

An original sociodemographic study questionnaire with 8 questions was used as a research tool, as well as a CPR quality assessment form. A model with the LLEAP software for SimPad was used to perform the practical test, and then the readout results were put into a specially constructed form to evaluate pre- and post-exercise activities. Subsections 1 through 3 provided scoring possibilities on a 0-1 scale, while subsections 4 through 8 provided percentage scores. The evaluation included:

1. the correct position for performing chest compressions;
2. compressions performed with the palm of the hand;
3. unjustified interruption of chest compressions;
4. overall compression quality [%];
5. compression rate [%];
6. compression frequency [%]
7. compression depth [%];
8. compression relaxation [%];
9. compression site location [%].

To analyze the statistical results, the normality of the variable distribution was determined using the Shapiro-Wilk test, and then the non-parametric Mann-Whitney U test for unrelated variables was used. Correlations between variables were tested using the r-Pearson test. All the results were considered relevant at $p<0.05$.

RESULTS

Characteristics of the study group

The study included 100 subjects, including 93 men and 7 women, whose mean age was M=30.84 (SD ± 10.95).

The marital status was as follows:

- single: 54% (n=54);
- married: 44% (n=44);
- divorcee: 1% (n=1)
- Widow/widower: 1% (n=1)

The vast majority of participants (98%) identified rural areas as their place of residence. Most declared secondary education (42%) and vocational education (24%). Among the remaining participants, undergraduate (16%), elementary (11%) education and master's (7%) degree were also indicated. During the study, the respondents were most often employed on an employment contract (63%), a contract (7%), a specific task contract (4%), and a commission agreement (3%). One in five respondents described their status as unemployed (20%), two of whom were looking for work. Among the participants, there were 54 firefighters, 8 senior firefighters, 5 group commanders, 5 section commanders, 3 platoon commanders, 1 audit committee chairman, 12 board members, 2 deputy chiefs, 6 chiefs and 4 VFD presidents.

Effectiveness of chest compressions

The authors verified nine quality parameters of chest compressions before (Figure 1) and after physical activity (Figure 2). The results of these tests are shown in Figures 1 and 2.

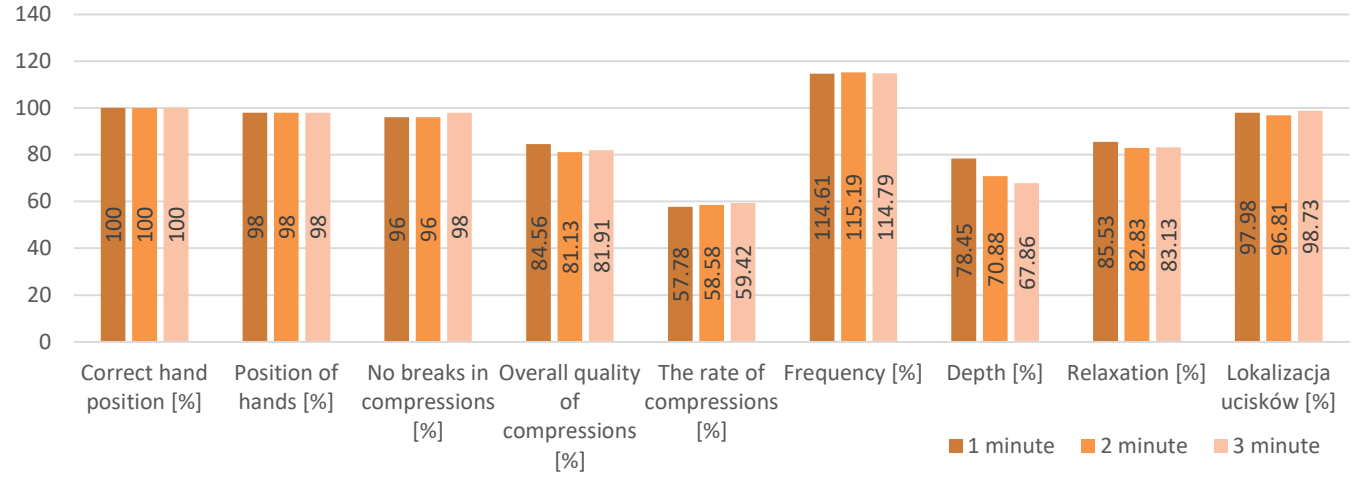

Figure 1. Quality of chest compressions before exercise.

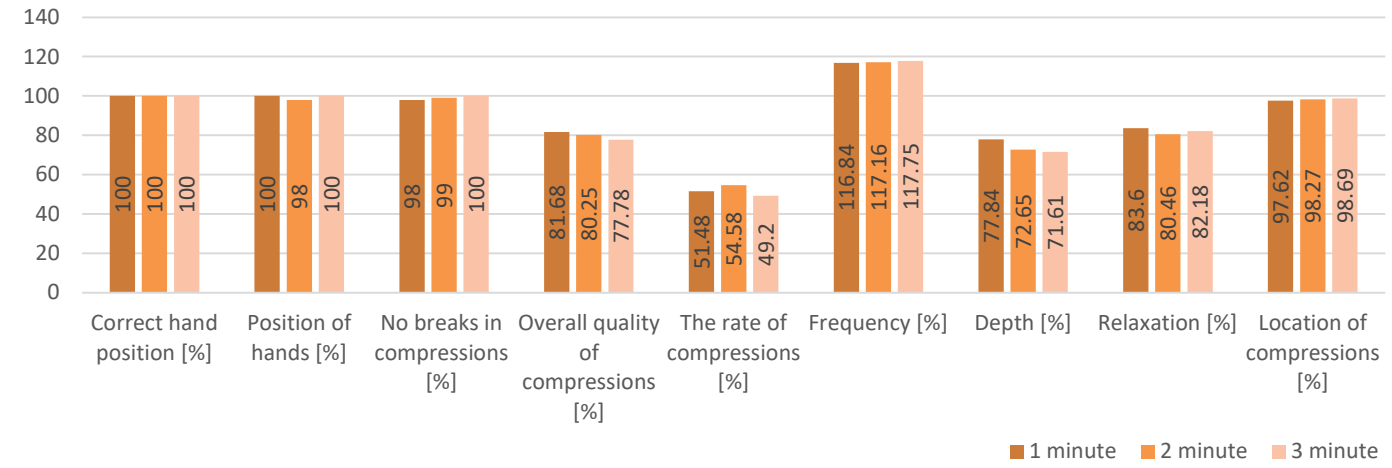

Figure 2. Quality of chest compressions after physical activity.

The analysis shows that the parameter of correct position during chest compressions measured both before and after physical activity was performed correctly by all subjects (100%). The average score of each firefighter in the aspect of hand positioning before the activity was 98%, with 100% indicated in the first and third minute, and 98% in the second minute. When taking into account the avoidance of interruptions in compressions, it averaged 96% in the stage before physical activity in the first and second minutes, and 98% in the third minute. As a result of fatigue, the score in each successive minute increased by 1 percentage point starting at 98% and ending at 100%. Analysis of the overall compression quality indicated that the average score was 84.56% in the stage before physicial activity during the first minute, 81.13% in the second minute and 81.91% in the third minute (Figure 3). After fatigue, the percentage was lower, with a decrease in quality compared to the first measurement, starting at 81.68% (p=0.281), through 80.25% (p=0.558), ending at 77.78% (p=0.243) in the third minute. The mean overall quality score of chest compressions was found to be statistically significantly higher in men (83.78%) than in women (65.90%) at the stage before physical activity (p=0.019), and borderline higher (81.00% vs. 65.33%) after physical activity (p=0.053). In summary, the overall quality of compressions in women was at a lower level than in men in both stages of the study process.

Those over 53 years of age had the best percentage score for the overall quality of chest compressions before physical activity (90.83%). The age groups were ranked as follows: 39-45 years (86.88%), 25-31 years (86.44%), 46-52 years (80.22%), 32-38 years (78.07%) and 18-24 years (77.85%). After exercise, firefighters in the >53 age group had the highest score again (90.78%). There was no statistically significant correlation of the compression quality to the age of the subjects, either before physical activity (p=0.277) or after physical activity (p=0.468).

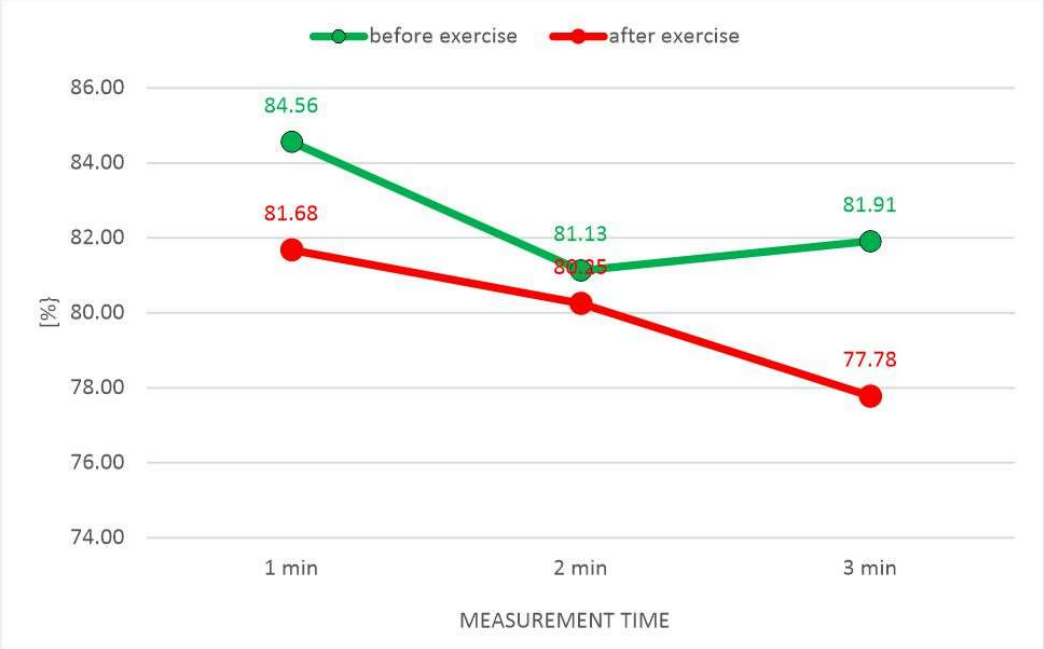

Figure 3. Correlation of overall chest compression quality.

The compression rate was expressed in the number of compressions per minute. The correct value to be achieved by participants was between 100-120/min. During the study, respondents managed to score within the foregoing range in every minute, both before and after physical activity. The lowest average (114.61/min) was obtained in the first minute before fatigue, while the highest was obtained in the third minute after fatigue (117.75/min). The subjects' depth results before physical activity in the first minute only were higher (78.45%) than their post-exercise results (77.84%). The average score in the second minute before physical activity was 70.88%, while it increased by 1.77% to 72.65% after physical activity. In the third minute, it had risen to 71.61%, and had reached 67.86% before physical activity. The next important element of effective chest compression is relaxation, where the values of correct relaxation were 85.53%, 83% and 83.13% before fatigue, respectively, while the participants scored lower after physical activity, with 83.60% in the first minute, 80.46% in the second minute and 82.18% in the third minute. The criterion assessed for the overall quality of chest compressions also showed no significant correlation with the firefighters' functional rank (before physical activity p=0.402; post-exercise p=0.635).

Both chest compression frequency (p_{1min}=0.479; p_{2min}=0.811; p_{3min}=0.098), depth (p_{1min}=0.872; $_{p2min}$=0.667; p_{3min}=0.430) and relaxation (p_{1min}=0.645; p_{2min}=0.380; p_{3min}=0.283) showed no statistically significant differences in readings during each of the three minutes of chest compressions before and after physical activity. However, a correlation was observed between the depth of compressions and the sex of the firefighters (before physical activity - males: 75.39% vs. females: 32.67% for p=0.018 and post-exercise - males: 76.10% vs. females: 46.62% for p=0.000), as well as thoracic relaxation and functional degree (before physical activity p=0.036; post-exercise p=0.023), as well as between depth and age (before physical activity p=0.015).

The last parameter evaluated was to assess the location of the chest compression site. The mean value did not show 100% at any stage of the study. In the third minute before physical activity, the evaluators obtained the highest mean (98.73%), with the lowest ones in the second minute also before physical activity (96.81%). All the results for this parameter differed slightly in percentage points between the lowest and highest mean values.

DISCUSSION

According to studies by authors such as Villela PB (2023), Perkins GD (2021), and Olasveengen TM (2021), rescuer fatigue has a major impact on the quality and effectiveness of the CPR performed [5,7,8]. The literature confirms that fatigue in rescuers can lead to the most common mistakes made during CPR. Lack of complete chest relaxation and prolonged time between life-saving actions, as well as inadequate and inaccurate numbers of compressions, are often the result of rescuers' fatigue. Unfortunately, the effectiveness of the cardiopulmonary resuscitation performed depends on these actions. It is less common to find literature that presents the issue of the quality of chest compressions performed by fatigued rescuers, especially firefighter rescuers, who are exposed to considerable physical activity even before first aid is administered.

In his work, Krzyżanowski K (2020) examined the topic of the quality of chest compressions under fatigue. In his study, he presented a comparison of teams consisting of two and three people. According to Krzyżanowski, the reaction time of a fatigued rescuer is prolonged, and so is the time for assessing the basic vital signs of the casualties. Assessment of airway patency, circulation, and rapid response to the patient's current condition increases the patient's chance of restoring vital functions. The author, noting the problem of prolonged pauses in chest compressions, noted a relationship involving the number of rescuers on the team. Three-person rescue teams operating during fatigue performed better in terms of rescue operation continuity than two-person teams operating during the same physical activity. The study showed that the actions of the three-person teams in terms of pauses between actions did not exceed 10 seconds, and maintenance of compression time was maintained at 60% of the entire CPR cycle. Teams with less persons performed relatively worse [9]. The literature raises the conclusion confirming the correlation that, despite fatigue, teams with a greater number of rescuers have significantly better results in carrying out rescue operations, thus increasing the chances of patient survival. For the past several years, there have also been publications such as Sell RE (2010) in which the authors studied the quality of chest compressions under fatigue in patients with out-of-hospital ventricular fibrillation. These studies also support the rule that it is easier to maintain greater attention to medical procedures and obtain the best possible results from the CPR performed in teams with more personnel [10].

Back to the issue of chest compression depth, according to the studies, emergency medical team members rarely exceeded 5 centimeters in chest compression depth, while teams with more people reached 4.5-5.5 centimeters in depth. In terms of compressions per minute (rate), the value slightly exceeded 120 compressions per minute [9].

In addition, it is worth noting a study by Idris AH (2012, 2015), in which the authors found an acceleration in the chest compression rate by rescuers operating during significant fatigue. Thus, increasing the number of chest compressions per minute generated an additional increase in subjects' fatigue during CPR activities, while decreasing the effectiveness of medical activities [11,12].

In the study conducted, the overall quality of the compressions carried out by the studied firefighters decreased under the influence of physical activity, yet this decrease was not as drastic. Chest compressions in the first minute after physical activity were worse by 2.88 percentage points than those before physical activity, and by only 0.88 in the second, and by 4.13 in the third minute. When analyzing sociodemographic factors affecting the quality of resuscitation, significant correlations were found with regard to overall quality of compressions and sex before fatigue ($p=0.019$), depth and gender before ($p=0.018$) and after physical activity ($p=0.000$), depth and age ($p=0.015$), relaxation and functional grade before ($p=0.036$) and after physical activity ($p=0.023$). Statistical analysis showed no statistically significant differences in the aspects of chest compression rate, depth and relaxation.

It should be noted that the study indicates a moderate effect of the subjects' fatigue on the quality of CPR. After 1 minute, a 0.61 percentage point reduction in chest depth values was found compared to before physical activity results, with a 1.77% reduction after 2 minutes, and a 3.75% reduction after 3 minutes. In terms of thoracic relaxation, there was also a decrease in value after physical activity, wherein the value decreased by 1.93 percentage points, by 2.37 in the second minute, and by 0.95 in the third minute. The study also indicated that the rate of chest compressions at 1 minute after physical activity was worse by 6.3 percentage points compared to before physical activity results, by 4% at the second minute, and by 10.22% at the third minute.

Limitations of the study: The study was conducted under controlled conditions, while the participants were not exposed to the stressors that accompany cardiopulmonary resuscitation on a casualty in an unprotected situation. In addition, in order to further investigate the effect of firefighter fatigue on the effectiveness of chest compressions, studies would need to be conducted on a larger group of subjects, under different conditions and with the test group subjected to greater physical activity.

CONCLUSIONS

In summary, the study identifies specific elements of chest compressions quality that require training in specific age groups, sexes and among representatives of selected firefighting functions. The effect of fatigue on the rescue operations carried out by the study group was not significant in terms of the entire group. The low percentage of correct quality and, above all, depth of chest compressions provided by women are the most notable. The group of firefighters aged 18-24 showed the worst percentage of quality in terms of depth and relaxation during compressions. Such a result can probably be dictated by the insufficient amount and level of training among young firefighters. The small number of studies concerning firefighter fatigue during resuscitation necessitates further detailed analysis.

SUPPLEMENTARY INFORMATION

Funding: *No fund was received related to this study.*
Institutional Review Statement: *The study was conducted according to the guidelines of the Declaration of Helsinki.*
Informed Consent Statement: *Not applicable*
Data Availability Statement: *The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.*
Conflicts of Interest: *The authors declare no conflicts of interest.*

REFERENCES

[1] „Act of September 8, 2006 on State Emergency Medical Services" Ustawa z dnia 8 września 2006 r. o Państwowym Ratownictwie Medycznym /(Dz. U. 2006 Nr 191 poz. 1410).

[2] Wakuła A. Obciążenia zawodowe strażaka-ratownika – ocena subiektywna. Bezpieczeństwo Pracy, 2009; 11: 16-18.

[3] Stępka-Tykwińska E., Basińska MA, Sołtys M, Piórkowska A. Selected personality traits as predictors of coping flexibility in a group of officers of the State Fire Service. Med Prac. 2019; 70(5): 555-565. doi: https://doi.org/10.13075/mp.5893.00823

[4] Merchant RM, Topjian AA, Panchal AR, et al. Part 1: executive summary: 2020 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. Circulation. 2020; 142(suppl 2): S337-S357. doi: https://doi.org/10.1161/CIR.0000000000000918

[5] Villela, PB. Improving Cardiopulmonary Resuscitation. Arq Bras Cardiol. 2023; 120(1). doi: https://doi.org/10.36660/abc.20220900

[6] Ziobro J. Teoretyczne i praktyczne konteksty funkcjonowania Ochotniczych Straży Pożarnych w Krajowym Systemie Ratowniczo-Górniczym. Aspekty prawno-organizacyjne i geograficzno-przestrzenne. Warszawa: Difin; 2019.

[7] Olasveengen TM, Semeraro F. Basic life support and systems saving lives. Current Opinion in Critical Care, 2021; 27(6): 617-622. doi: https://doi.org/10.1097/MCC.0000000000000897

[8] Perkins GD, Gräsner JT, Semeraro F, Olasveengen T, Soar J, Lott C, et al. European resuscitation council guidelines 2021: executive summary. Resuscitation, 2021; 161: 1-60. doi: https://doi.org/10.1016/j.resuscitation.2021.02.003

[9] Krzyżanowski K, Ślęzak D, Dąbrowski S, Zuratyński P, Mędrzycka-Dąbrowska W, Buca P, et al. Comparative Analysis of the Effectiveness of Performing Advanced Resuscitation Procedures Undertaken by Two- and Three- Person Basic Medical Rescue Teams in Adults under Simulated Conditions. Int J Environ Res Public Health. 2021; 18(9): 4834. doi: https://doi.org/10.3390/ijerph18094834

[10] Sell RE, Sarno R, Lawrence B, Castillo EM, Fisher R, Brainard C, et al. Minimizing pre- and post-defibrillation pause increases the likelihood of return of spontaneous circulation (ROSC). Resuscitation, 2010; 81(7): 822-825. doi: https://doi.org/10.1016/j.resuscitation.2010.03.013

[11] Idris AH, Guffey D, Pepe PE, Brown SP, Brooks SC, Callaway CW, et al. Chest compression rates and survival following out-of-hospital cardiac arrest. Crit Care Med. 2015; 43(4): 840-848. doi: https://doi.org/10.1097/CCM.0000000000000824

[12] Idris AH, Guffey D, Aufderheide TP, Brown S, Morrison LJ, Nichols P, et al. Relationship between chest compression rates and outcomes for cardiac arrest. Circulation 2012; 125: 3004-3012. doi: https://doi.org/10.1161/CIRCULATIONAHA.111.059535