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Paramedic equipment bags: How their position during out-of-hospital cardiopulmonary resuscitation (CPR) affect paramedic ergonomics and performance

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ABSTRACT

This study investigates how the positions of paramedic equipment bags affect paramedic performance and biomechanical loads during out-of-hospital Cardiopulmonary Resuscitation (CPR). An experiment was conducted in which 12 paramedic teams (each including two paramedics) performed in-situ simulations of a cardiac-arrest scenario. CPR quality was evaluated using five standard resuscitation measures (i.e., pre- and post-shock pauses, and compression rate, depth and fraction). The spinal loads while lifting, pulling and pushing the equipment bags were assessed using digital human modeling software (Jack) and prediction equation from previous studies. The results highlight where paramedics are currently choosing to position their equipment. They also demonstrate that the positions of the equipment bags affect CPR quality as well as the paramedics' work efficiency, physiological effort and biomechanical loads. The spinal loads ranged from 1901 to 4030N; furthermore, every occasion on which an equipment bag was lifted resulted in spinal forces higher than 3400N, thus exceeding the maximum threshold stipulated by the National Institute for Occupational Safety and Health. 72% of paramedics' postures were categorized as high or very high risk for musculoskeletal disorders by the Rapid Entire Body Assessment. Guidelines related to bag positioning and equipment handling might improve CPR quality and patient outcomes, and reduce paramedics' risk of injury.

1. Introduction

The work of paramedics requires a high level of technical competence and involves both quick decision-making and the ability to act accurately and swiftly (Bitan, 2017; Myers et al., 2008). Paramedics provide immediate life support such as Cardiopulmonary Resuscitation (CPR) during out-of-hospital cardiac arrest. Performing effective CPR depends on multiple measurable parameters, such as compression depth (cm) and rate (bpm), pre/post-shock pauses (sec), and the percentage of time in compressions (Sell et al., 2010; Cheskes et al., 2014; Wik et al., 2005).

Paramedics are exposed to a risk of injury that is approximately three times higher than the average for all occupations; the annual rate of paramedic injuries that result in lost working days is 349.9 per 10,000 full-time workers, in comparison to a rate of 122.2 for all private industry occupations (Maguire and Smith, 2013). The cause of 94% of the injuries is a musculoskeletal disorder, especially strains and sprains (62%) and back pain (18.8%). During their out-of-hospital work, paramedics are forced to adopt unhealthy working postures (Prairie and Corbeil, 2014) and to perform tasks that require the lifting and moving of heavy objects while in non-optimal positions (Fischer et al., 2017). The leading cause of paramedics' injuries is body movement, with 90% attributed to lifting, carrying, or handling a patient and/or equipment (Reichard et al., 2017). However, Reichard et al. (2017) investigated the number of injuries by conducting a survey; they did not perform experiments, take measurements or conduct simulations to investigate the actual biomechanical loads acting on the paramedics' bodies during patient or equipment handling. Furthermore, they did not investigate CPR quality, work efficiency or physiological effort.

Several studies have suggested ergonomics interventions (Karsh et al., 2001) to reduce the biomechanical loads and risk of injury during patient transfer (e.g., Armstrong et al., 2017; Lavender et al., 2007;

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Conrad et al., 2008; Prairie et al., 2016; Lad et al., 2018). Others have investigated the physiological and biomechanical loads acting on paramedics' bodies while conducting chest compressions during CPR (Dainty and Gregory, 2017; Tsou et al., 2009, 2014; Heidenreich et al., 2006). However, none of these studies investigated the effects of equipment handling on paramedics' performance, physiology and biomechanics; nor did they mention equipment handling as a variable worthy of study.

To the best of our knowledge, no standardized guidelines or instructions exist regarding where paramedics should position their bags around the patient. Several studies have shown that equipment position affects both the performance of workers and their risk of injury (Harari et al., 2017, 2018, 2019; Ben-Gal and Bukchin, 2002; Shewchuk et al., 2017). However, to the best of our knowledge, no study has investigated whether the positions of paramedics' equipment around the patient affect the quality of CPR or the paramedics' work efficiency, effort and biomechanical loads.

The objective of the current study is threefold: First, to investigate where paramedics are currently choosing to position their equipment around the patient during out-of-hospital cardiac arrest. Second, to investigate CPR quality and paramedics' work efficiency, effort and biomechanical loads during out-of-hospital CPR. Finally, to investigate whether, and to what extent, the positions of the equipment around the patient affect CPR quality and paramedics' work efficiency, physiological effort and biomechanical loads.

2. Methods

This study presents an experiment conducted in collaboration with Magen David Adom (MDA), which is the Israeli national emergency medical services (EMS).

2.1. Participants

A total of 24 participants (12 male and 12 female) were recruited to the experiment from the Department for Emergency Medicine at Ben-Gurion University of the Negev. They were a mix of experienced, certificated paramedics and paramedic students with some field experience. The paramedics were grouped into teams, each team comprising two paramedics - a senior and a junior member. In order to reduce the possibility that some of the paramedics had experience working together, which might have affected their performance, the teammates in each team were selected randomly. The senior teammate in each team was a certificated paramedic or a student in his/her last year of studies. The junior teammate was a student in his/her second year of studies. All paramedics (junior and senior) had experience of at least 24 field shifts in an ambulance, each of 8 h, and had performed at least 20 simulations of out-of-hospital cardiac arrest during their training. All paramedics passed a screening questionnaire to ensure that they did not suffer from a heart condition or a musculoskeletal disorder (MSD) and were not sick or injured. The experimental protocol was approved by the ethics committee of the Ben-Gurion University of the Negev.

2.2. Experimental design

The experiment included 12 paramedic teams, each of which performed two simulations of out-of-hospital cardiac arrest CPR on a simulated patient mannequin (SimMan4000™ by Laerdal). Each simulation lasted 10 min during which the paramedics carried out a standard CPR procedure of the Israeli EMS (including chest compressions, bag-valve-mask ventilation, electric shock, drug injection, etc.). During the simulations, the paramedics used the same equipment bags that would be used in a real event – an air-way bag, a medication bag, a vital-signs monitor-defibrillator, and a small oxygen tank (Fig. 1). The in-situ simulations focused on the technical work performed by the paramedics and not on their clinical decision-making processes.

The mass of the bags, and the force required to push or pull the equipment along the floor of the lab, were measured using an HP-500 digital force gauge (M&A Instruments Inc.). The bags were pulled/pushed in a slow movement at an angle similar to that which would be created by a human hand. These measurements were performed on the laboratory floor with ceramic tiles that are very common in buildings and homes in Israel. We recorded the maximum force that was applied during the push/pull task and then calculated the average of the maximum force over three trials (Table 1).

The CPR simulations were conducted in the Human-Systems Integration in Healthcare Lab at Ben-Gurion University of the Negev. A wooden frame (see Fig. 2) with dimensions of $225 \times 270 \times 20$ cm (width × length × height) was located at the center of the lab. This frame simulated the available area in a small-sized bedroom and constrained the working area for the paramedics. The opening in the frame to enter

Table 1
The mass of each bag and the force required to push or pull each bag.

Equipment bag	Mass [kg]	Force required to push/pull the equipment [N]
Air-way bag	3.4	21.9
Vital-signs monitor-defibrillator	6.5	47.6
Medication bag	9.3	33.5
Oxygen tank	3.2	27.2

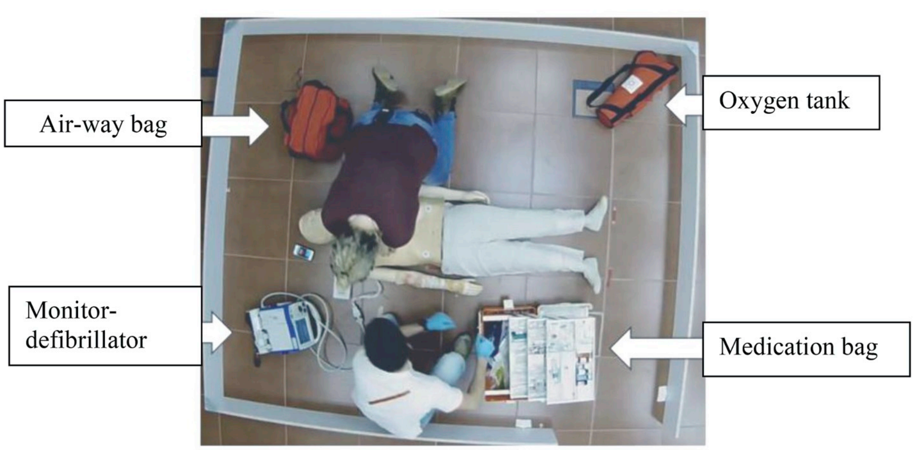

Fig. 1. A simulated scenario of CPR executed by a team of two paramedics, handling four equipment bags. The senior paramedic is marked with a red line on the back of his/her shirt. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

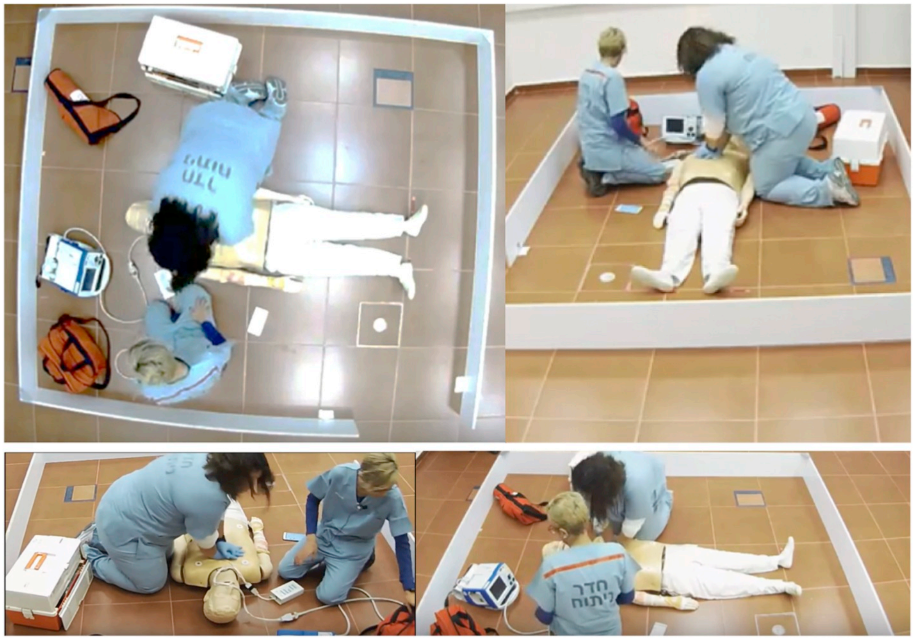

Fig. 2. The four cameras angles that recorded the experiments.

and exit was 0.7 m. The simulated scenarios were video-recorded from four angles using four video cameras (AXIS M1065-L Network Camera by Axis Communications) at a rate of 25 frames per second (Fig. 2). The four cameras were connected to a Noldus Media Recorder using four channels and the four video clips were merged into a unified video clip for each simulation. Using a dedicated software tool (Observer XT by Noldus), the authors manually identified the paramedics' interactions with the equipment around the patient. An interaction with an equipment bag was defined as an event in which a bag was either moved (i.e., lifted, pushed or pulled) or used without being moving (e.g., extracting equipment from a bag). Each interaction was defined by two video frames: 1) the frame in which the interaction began (i.e., the frame in which the paramedic touched the bag for the first time during the event); and 2) the frame in which the interaction ended (i.e., the frame in which the paramedic touched the bag for the last time during the event). We used the marked grid on the floor to indicate the original position of each bag. The position was defined based on which of the 45 × 45 cm squares in the grid (see Fig. 3) the bag occupied, as explained in Section 2.5.

2.3. Experimental procedure

Before starting the simulation, the paramedics were introduced to the four equipment bags and the simulated mannequin, and were given a description of the CPR scenario. This description simulated one that paramedics typically receive from dispatch when a patient suffering from a cardiac arrest has been identified. Upon entering the lab, the paramedics were instructed to work only inside the wooden frame. They did not receive any information regarding where to position each equipment bag during the simulation.

Having received the dispatch description, at the beginning of the simulation, the paramedics checked for a pulse, breathing and gasping, as is standard in their training. They started CPR when no signs of life were observed on the mannequin. The paramedics did not receive any instructions regarding the treatment protocol and were able to decide what sequence of operations to perform (e.g., chest compressions, drug injections, electric shocks). Furthermore, the paramedics did not receive any instructions regarding the distribution of their roles during the simulation. However, as is stipulated in their training, the electric shock and drug injection were performed by the senior paramedic. The rest of the tasks (chest compressions, bag-valve-mask ventilation) were performed by both teammates.

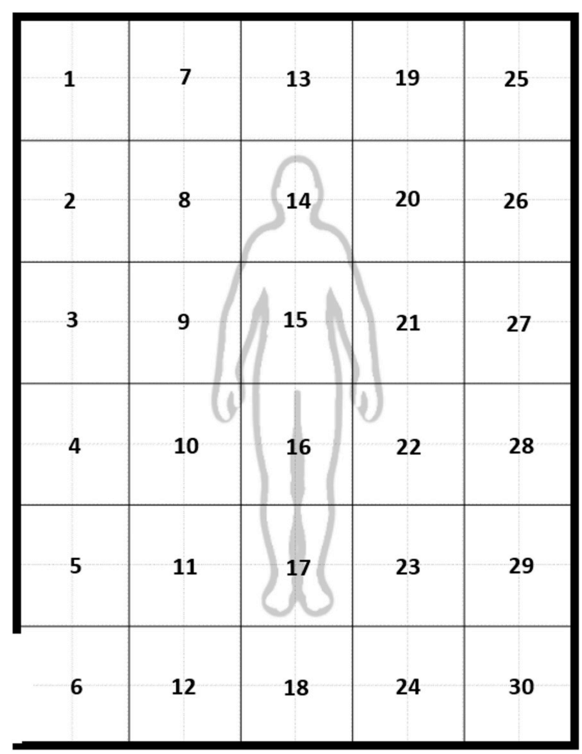

Fig. 3. The grid marked on the floor that was used to identify the positions of the equipment bags. The black bold outline represents the wooden frame.

Each team completed two simulations, where each simulation lasted 10 min and was followed by a 15-min break. The simulation duration was set to 10 min, since this duration enabled 5 CPR cycles (of 2 min each, as instructed by the AHA, 2015 protocol). Furthermore, a 10-min duration was considered sufficient to perform advanced procedures (i.e., electric shock, drug injection). The official simulation time began when the paramedics entered the simulation room (the wooden frame).

2.4. Performance measures

The performance measures (dependent variables) were selected to measure the quality of the CPR procedure and the paramedics' work efficiency, physiological effort and biomechanical loads. The independent variables were the initial positions of each of the four equipment bags (medication, monitor-defibrillator, air-way, oxygen) during the simulation. In this manuscript we refer to all four equipment items as bags.

2.4.1. Quality of CPR

To evaluate the quality of the CPR procedure, we used standard resuscitation measures: 1) The compression depth, which is recommended by the American Heart Association (2015) to be between 5 and 6 cm. The performance measure (%CD) was defined as the % of compressions within a depth range of 5–6 cm. 2) The compression rate, which is recommended by the American Heart Association (2015) to be between 100 and 120 bpm. The performance measure (%CR) was defined as the % of compressions with a rate of 100–120 bpm. 3) The pre-shock pause (PRSP) in seconds, which is the time between the last compression prior to the electric shock and the shock. 4) The post-shock pause (POSP), which is the time between the electric shock and the subsequent compression. Minimizing these pauses has been found to increase CPR success rate (Cheskes et al., 2014; Sell et al., 2010). 5) The compression fraction (CF; %), which is the length of time for which compressions are performed as a percentage of the total resuscitation duration (i.e., 10 min, starting from the moment the paramedics entered the simulation room). Maximizing the compression fraction has been found to increase CPR success rate (Christenson et al., 2009).

All of the above are standard measures of resuscitation quality, found to affect CPR procedure success rates during out-of-hospital cardiac arrest (Wik et al., 2005). The monitor-defibrillator (Zoll™, R series) was connected to the sternum of the patient mannequin (the sensor placement on the sternum was identical for all simulations). The software embedded in the monitor-defibrillator calculated the compression depth and rate, the pre-shock pause, the post-shock pause, and the compression fraction. The CPR quality measures were calculated separately for each simulation and considered all the compressions during a simulation (performed by both paramedics).

2.4.2. Work efficiency

The work efficiency parameters provide an indication of the time spent on activities that were not dedicated to the CPR procedure. The following parameters were measured: 1) the total number of times the paramedics changed their position during the simulation (TNPC); 2) the percentage of the simulation duration that was spent changing positions (%TPC); and 3) the total number of steps walked by the paramedics during the simulation (TNS). The work efficiency measures were calculated for each simulation and consider the actions of both paramedics combined (e.g., TNS is the number of steps performed by both paramedics during a given simulation).

2.4.3. Physiological effort

The physiological effort parameters included both objective and subjective measures. The objective measures were the paramedics' peak heart rate (PHR) and mean heart rate (MHR), which were measured using a Garmin™ watch (Forerunner 235™) placed on the paramedics' wrists. The Forerunner 235 (as well as a similar model by Garmin) was found to provide accurate measurements of heart rate during various physical activities (Claes et al., 2017; Støve et al., 2019). The subjective physiological measure was the Borg test for the perceived level of exertion (Borg, 1998), which results in a score between 6 and 20, where 6 represents very light effort and 20 represents maximal effort. The Borg test was conducted by asking the paramedics to grade their level of exertion after each simulation. Both the heart rate and the Borg measure indicate the paramedics' level of exertion during the simulation and may predict the level of fatigue. The effort measures were calculated for each simulation and represent the average values of the paramedics (i.e., the Borg measure for a given simulation represents the average of the two Borg scores corresponding to the two paramedics).

2.4.4. Biomechanical loads

A main focus of this study was to investigate the biomechanical loads acting on the paramedics' bodies due to handling the bags, as well as the risk of injury due to these loads. The biomechanical loads were evaluated using both direct measures and ergonomic assessments.

2.5. Direct measures

The direct measures of biomechanical load were the number of times the equipment bags were handled (i.e., lifted, pushed, pulled or used without being moved) and the cumulative force during the simulation (N) that was required to move (i.e., lift, push or pull) the bags. The number of times the paramedics handled their equipment (TMMH) was calculated using Equation (1). The cumulative force (TMLP) that was required for lifting, pushing and pulling the bags was calculated using Equation (2):

$$TMMH = \sum_{k=1}^{2}\sum_{j=1}^{4}\sum_{i=1}^{4} MMH_{i,j,k} \tag{1}$$

$$TMLP = \sum_{k=1}^{2}\sum_{j=1}^{3}\sum_{i=1}^{4} MMH_{i,j,k}{}^{*}F_i \tag{2}$$

where k is the paramedic indicator ($k\ = 1$ for the senior paramedic, $k = 2$ for the junior paramedic), j is the type of Manual Material Handling (MMH) task performed by the paramedic ($j = 1$ for lifting, $j = 2$ for pushing, $j = 3$ for pulling, and $j = 4$ for using a bag without moving it), and i is the equipment bag indicator ($i = 1$ for the oxygen tank, $i = 2$ for the air-way bag, $i = 3$ for the medication bag, and $i = 4$ for the monitor). $MMH_{i,j,k}$, is the number of times paramedic k conducted MMH task j on bag i. F_i is the force (N) required to lift, push or pull equipment bag i (see Table 1). The direct performance measures were calculated for each simulation and include the actions of both paramedics (e.g., TMMH is the number of occasions on which both paramedics handled an equipment bag during one simulation).

2.6. Ergonomic assessments

To further assess the biomechanical loads, as well as the paramedics' risk of MSD, we used the following tools:

The Rapid Entire Body Assessment (REBA; Hignett and McAtamney, 2004) assessed the risk level for MSD based on the paramedics' postures and loads. The REBA score for an interaction was manually calculated by one of the authors using the video recording. This was carried out for all the occasions on which the paramedics used an equipment bag. For each occasion, the REBA score was calculated using the video frame in which the paramedic's posture was the worst (e.g., maximal trunk bending, arm reaching, etc.). The REBA tool has been shown in a recent study to result in high intra-rater reliability (Schwartz et al., 2019). In our study, to achieve the highest possible accuracy, the REBA measurements were conducted offline in a video laboratory, where each posture was measured from the video (frame-by-frame analysis). The video rate was 29 frames per second. The performance measure was then the mean REBA score throughout the simulation (MREBA). Thus MREBA averages over all the REBA scores of both paramedics during one simulation and represents the mean posture for a paramedic when handling an equipment bag.

We also determined the range of spinal compression forces acting on the paramedics when they lifted, pushed and pulled the bags, using the following methods. The peak compression forces acting on the paramedics' spines while *lifting* each of the equipment bags were assessed using the equation of Hoozemans et al. (2008). In this equation, the load mass was the mass of the lifted bag (see Table 1) and the handle height was set to 20 cm above the floor (the approximate height from which the bags were lifted).

The peak compression forces acting on the paramedics' spines while *pushing* and *pulling* the equipment bags were calculated using computer simulations of the tasks in Digital Human Modeling software, Jack™ (Siemens PLM). The simulated paramedics in Jack consisted of a virtual male with a height of 1.75 m and a weight of 79 kg, and a female with a height of 1.63 m and a weight of 63 kg. These heights and weights represent the anthropometrics of a median male and female, according to the ANSUR database (Gordon et al., 1989). For each equipment bag and each virtual human (male/female), two conditions were investigated in Jack, as explained below. In all computer-simulations, the virtual human pushed or pulled the bag with both hands while kneeling (as was observed in the experiment). In the first condition, the bag was located in close proximity to the virtual human's knees (25 cm), while in the second condition, the bag was located at the farthest distance that still enabled the bag to be pushed or pulled without changing the kneeling position (90 cm). These two distances were chosen based on observations of the videos of the experiments, which showed that in some cases, the bag was located close to the paramedics' knees, while at the other extreme the paramedics had to fully extend in order to reach to the bag. Thus the use of these two distances allowed us to determine the range of possible values of the spinal forces during bag handling. This could be useful when comparing the compression forces due to bag handling with the forces reported for other paramedics' activities, such as chest compression and patient handling.

2.7. Statistical analyses

The positions in which paramedics currently choose to place their equipment bags were represented using heat maps that show the frequencies of the initial positions of each bag around the patient. In order to investigate whether the positions of the bags affect the quality of CPR and the paramedics' work efficiency, effort and biomechanical loads, MANOVA tests were conducted using the Lawley-Hotelling trace. For each of the four equipment bags, four separate MANOVA tests were conducted. The dependent variables in the first test were the performance measures that evaluate CPR quality (%CR, %CD, CF, PRSP, POSP; see Section 2.4.1). The remaining tests respectively investigated the paramedics' work efficiency (TNPC, %TPC, TNS; see Section 2.4.2), their physiological effort (PHR, MHR, Borg; see Section 2.4.3), and the biomechanical loads acting on their bodies (TMMH, TMLP, MREBA; see Section 2.4.4). The independent variable in each test was the initial position of the equipment bag under investigation (i.e., the medication bag, monitor-defibrillator, air-way bag, or oxygen tank). The null-hypothesis of each MANOVA test (H_0) was that the initial position of the bag does not significantly affect any of the relevant performance measures (e.g., in the case of the MANOVA test for CPR quality, that it does not affect %CR, %CD, CF, PRSP or POSP). Therefore, we reject our null-hypothesis when $p < 0.05$. Due to the small number of observations, we assumed independency of each bag's location and did not include interactions between the independent variables. We defined eight possible initial positions for each bag: 1) above the patient's head (square 13 in Fig. 3); 2) below the patient's feet (square 18); 3) upper left side of the patient (square 1, 2, 7, or 8); 4) upper right side of the patient (square 19, 20, 25 or 26); 5) middle left side of the patient (square 3, 4, 9 or 10); 6) middle right side of the patient (square 21, 22, 27 or 28); 7) lower left side of the patient (square 5, 6,11 or 12); 8) lower right side of the patient (square 23, 24, 29 or 30).

In addition to carrying out MANOVA tests, we determined whether there was a difference between the senior and junior paramedics in terms of their physiological effort and work efficiency measures. This was carried out by performing t-tests (in which the significance level was set at $p < 0.05$). All statistical analyses were performed using the R-studio environment Team, 2017. The types of assessment undertaken in this study, along with the numerical analyses carried out for each type of assessment, are summarized in Table 2.

3. Results

3.1. Paramedics' choices for the initial positions of the equipment bags

The heat map of the initial positions (Fig. 4) reveals that the medication bag was most frequently placed to the left of the patient, between the head and the feet (Fig. 4A). The initial position of the air-way bag was most frequently above the patient's head on the left side (Fig. 4B). The monitor's initial position was most frequently on the left side of the head (Fig. 4C). Finally, the oxygen tank was most frequently positioned on the right side of the head (Fig. 4D).

3.2. Investigation of the CPR quality measures

The mean and standard deviation (SD) of each of the CPR measures during the experiment (i.e., calculated across all simulations) are presented in Table 3. The percentage of compressions that complied with the CPR recommended rate (100–120 bpm) ranged from 1% to 99%. In order to validate this finding, the simulations with the extreme values were manually investigated by the authors (i.e., the compression rate was manually measured from the video). The validation shows that indeed, in one simulation, only 1% of compressions were within the recommended range of rates, while in another simulation, 99% of compressions complied with the recommended rates. The percentage of compressions that complied with the CPR recommended depth (5–6 cm) ranged from 4% to 68%. The duration of the pre- and post-shock pauses ranged from 1 to 21 s and 1–7 s, respectively. The proportion of the total resuscitation time that was spent performing compressions (the compression fraction) ranged from 72% to 96%.

3.3. Evaluation of manual material handling during out-of-hospital CPR

In this subsection, we present summary statistics for the three variables related to MMH, namely, work efficiency, physiological effort and biomechanical loads. The mean and standard deviation of the work efficiency measures are summarized in Table 4. The paramedics changed their position between 4 and 24 times per simulation (total for both teammates), and spent between 2.5% and 12.5% of the simulation duration changing positions. Due to these position changes, the paramedics walked between 8 and 57 steps. It was also found that the senior

Table 2
Summary of the assessment types, the measures that are relevant to these assessments and the numerical analyses used.

Assessment type	Measures	Analyses
CPR quality	%CR, %CD, CF, PRSP, POSP	MANOVA
Work efficiency	TNPC, %TPC, TNS	MANOVA, *t*-test comparison between teammates
Effort	PHR, MHR, Borg	MANOVA, *t*-test comparison between teammates
Biomechanical loads	TMMH, TMLP, MREBA, spinal compression forces	MANOVA, computer simulation (Jack)

%CR - compressions within rate, %CD - compressions within depth, CF - compression fraction, PRSP - pre-shock pause, POSP - post-shock pause.
TNPC - total number of times the paramedics change their position, %TPC - percentage of the simulation duration that was spent changing positions, TNS - total number of steps walked by the paramedics.
PHR - peak heart rate, MHR - mean heart rate, Borg - score of Borg test for perceived level of exertion.
TMMH - number of times the paramedics handled their equipment, TMLP - cumulative force that was required for lifting, pushing and pulling the bags, MREBA - mean REBA score.

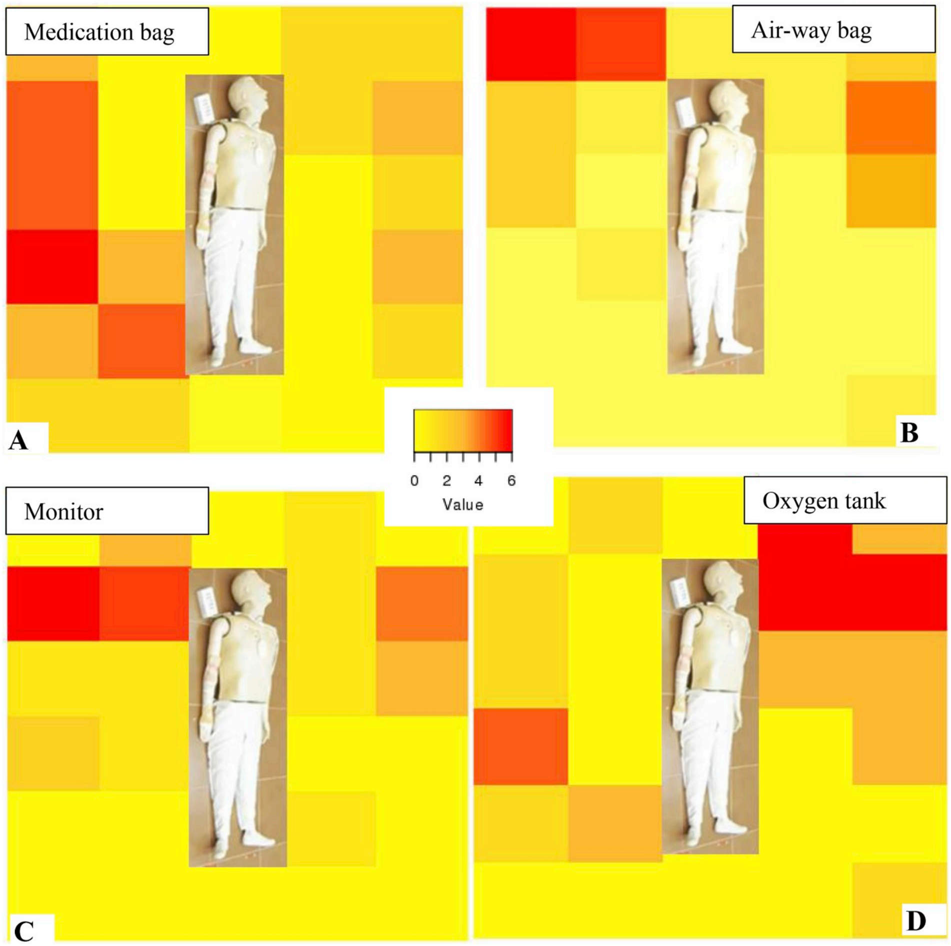

Fig. 4. Heat maps representing the frequencies with which the paramedics initially positioned the equipment bags: A) medication bag; B) air-way bag; C) monitor; D) oxygen tank.

Table 3
The mean and standard deviation (SD) of each of the CPR measures during the experiment.

	Mean	SD
Compressions within recommended rate (%)	68	43
Compressions within recommended depth (%)	27	20
Pre-shock pause (s)	2.8	4.6
Post-shock pause (s)	2.8	1.3
Compression fraction (%)	91	7.4

Table 4
The mean and standard deviation (SD) of each of the work efficiency measures during the experiment.

	Mean	SD
Number of times the paramedics changed position	12.6	5.6
Percentage of the simulation duration that was spent changing positions (%)	7	2.5
Total number of steps walked by the paramedics during the simulation	28	12.4

paramedics moved more than the junior paramedics – on average they changed positions 3 more times, spent 7 more seconds changing positions and walked 4 more steps (p-value<0.05).

The mean and standard deviation of the physiological effort measures are summarized in Table 5. The paramedics' mean heart rate during the 10 min of the CPR simulation ranged from 84 to 149 bpm, while their peak heart rate ranged from 106 to 186 bpm. The paramedics' perceived level of exertion using the Borg scale ranged from 6 to 19. No significant difference was found between the senior and junior paramedics in terms of their heart rate or perceived level of exertion (p-value>0.05).

The mean and standard deviation of the biomechanical load measures are summarized in Table 6. In total, the paramedics handled the bags (TMMH) between 3 and 19 times per simulation. This metric includes lifting, pushing, pulling, and using the bags without moving them. The mean cumulative force required to move the equipment bags during the simulation (TMLP) ranged from 0 to 313 N. The simulation with the maximal cumulative force (313 N) was the same simulation as that mentioned above with the highest number of equipment bag movements. However, in 31% of the simulations, the equipment bags were not moved (i.e., lifted, pushed or pulled) on even one occasion, which resulted in 0 N force. On average, the equipment bags were lifted 0.6 times and pushed or pulled 1.7 times (the total of both of these actions) per simulation. The highest number of bag movements during one simulation was 9, due to 2 lifts, 5 pushes and 2 pulls. The average

Table 5
The mean and standard deviation (SD) of each of the physiological effort measures during the experiment.

	Mean	SD
Peak heart rate (bpm)	156	21.4
Mean heart rate (bpm)	123	16.4
Borg	11.6	2.7

Table 6
The mean and standard deviation (SD) of each of the biomechanical load measures during the experiment.

	Mean	SD
Number of times bags were handled	6.8	4.7
Total force required to move the bags (N)	89	101
Mean REBA score	8	1.5

number of occasions on which equipment bags were used without being moved was 4.7 per simulation. The final row in Table 6 shows the mean and standard deviation of MREBA, the mean REBA score throughout the simulation.

Since the risk of MSD is a main focus of this study, in the remainder of this section, we examine variables that shed light on this issue in more detail. The REBA tool, which considers the paramedics' postures and loads, and assesses their risk of MSD, resulted in scores between 4 and 12 (Fig. 5A). A score of 4 represents a medium risk of MSD, with the recommendation to further investigate the task and to change it soon, while a score of 12 represents very high risk of MSD with the recommendation to implement immediate changes. The average REBA score (Table 6) was 8 (SD = 1.5), which represents a high risk of MSD with the recommendation to investigate and implement changes. All of the postures while using the equipment bags resulted in at least a medium risk-level for injury, with 72% of the postures resulting in high or very high risk of MSD (Fig. 5B).

The peak compression forces acting on the spine as a result of lifting the equipment bags (while standing) were predicted using the equation of Hoozemans et al. (2008) and ranged from 3697 N to 4030 N (Table 7). The peak compression forces acting on the spine as a result of pushing and pulling the equipment bags (while kneeling) were calculated using the Lower Back Analysis (LBA) tool of the Jack software and ranged from 1901 N to 3673 N (Table 7).

3.4. The effect of the positions of the equipment bags on CPR quality and ergonomics

The results of the MANOVA tests are presented in Table 8. The main findings can be summarized as follows: The CPR quality and the biomechanical loads were influenced by the positions of all four equipment bags. The work efficiency was influenced by the positions of the medication bag and oxygen tank. The paramedics' effort was influenced by the positions of the medication bag and monitor-defibrillator.

4. Discussion

4.1. Paramedics' choices for the positions of the equipment bags

Our results show that the bag positions affect the CPR and ergonomics measures. Yet paramedics in the MDA (the Israeli national emergency medical services) do not receive any instructions or guidelines regarding where to position the equipment bags around the patient. Thus, the results of this study represent the paramedics' personal choices. Since all the paramedics had experience in out-of-hospital CPR, these choices (see Fig. 4, Section 3.1) are likely to represent the paramedics' preferences based on their work experience and training. It is possible that the bags' positions were also affected by other factors, such as the procedures performed by the paramedics and the way in which the roles were distributed between them. The monitor, air-way bag and oxygen tank were mostly positioned around the shoulders and head of the mannequin (68% of the simulations), while the medication bag was mostly positioned lower down, between the shoulders and the foot of the mannequin (65% of the simulations).

4.2. Effect of bags' positions on CPR quality

The technical parameters that we used to measure CPR quality are crucial indicators that are known to be correlated with patient outcomes (American Heart Association, 2015). Our results demonstrate that all the measured parameters of CPR quality were influenced by the bags' positions. A detailed explanation of why the bags' positions affect CPR quality is provided in Section 4.5. These preliminary results suggest that instructions given to paramedics specifying where to position the bags around the patient might have the potential to improve CPR quality and, as a result, to improve the chances of patient survival.

4.3. Ergonomic evaluation of MMH tasks during CPR

On average the paramedics moved (lifted, pushed and pulled) the equipment bags 2.3 times per simulation. The spinal compression forces during these lifting, pushing and pulling tasks ranged from 1901 N to 4030 N. Thus in some cases, the spinal compression forces exceeded the maximal value of 3400 N recommended by the National Institute for Occupational Safety and Health NIOSH (Waters et al., 1993). This suggests that the MMH tasks conducted during the CPR procedure might result in a musculoskeletal disorder. Further, these values are higher than the peak compression forces that have been reported for conducting chest compressions (approximately 1731 N for a paramedic weighing 75 kg; Tsou et al., 2009). This emphasizes the importance of including the equipment handling tasks in the ergonomics assessment. The spinal forces in the current study may also be compared with those that arise during patient transfer (Lad et al., 2018; Prairie et al., 2006). Such comparisons show that in some cases the spinal forces during equipment handling are larger (c.f. Lad et al., 2018), while in other cases, they are lower (c.f. Prairie et al., 2016). The discrepancy between these two comparisons could be due to differences in experimental design, including the different methods used to calculate the forces in each study (i.e., Jack vs. 3DMatch vs. 3DSSPP). Thus, future studies should compare the forces due to equipment handling and patient transfer using a consistent experimental design.

The REBA scores during the equipment handling averaged 8, which is categorized as a high-level risk of injury. The high scores were mainly due to (a) excessive trunk flexion, bending and twisting and (b) upper arm flexion. Most of the cases of awkward posture occurred when the

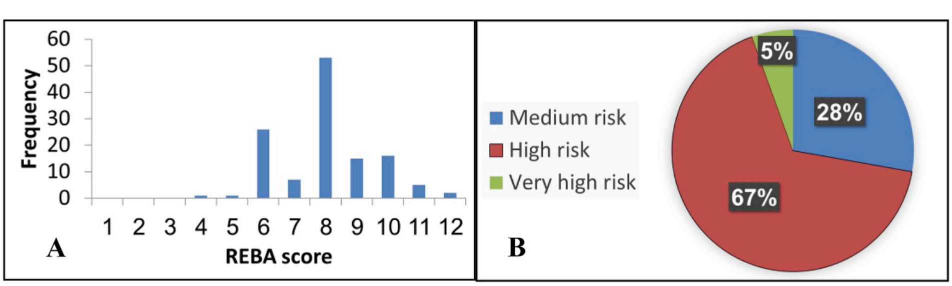

Fig. 5. The REBA scores for the postures of the paramedics when using the equipment bags: A) frequency of each score; B) percentage of postures in each risk-level for MSD.

Table 7
The peak compression forces (N) acting on the L5/S1 vertebrae while lifting each equipment bag and while pushing/pulling each equipment bag close/far from the body.

Equipment bag	Lifting	Pushing (close-25 cm)		Pushing (far-90 cm)		Pulling (close-25 cm)		Pulling (far-90 cm)	
		Female	Male	Female	Male	Female	Male	Female	Male
Medication bag	4030	1857	2079	3239	3620	1769	1960	2837	3370
Monitor- defibrillator	3877	1883	2109	3276	3673	1734	1986	2884	3420
Air-way bag	3708	1823	2045	3207	3570	1710	1901	2833	3310
Oxygen tank	3697	1824	2047	3306	3575	1690	1911	2937	3319

Table 8
The MANOVA results, which consist of the numerator and denominator degrees of freedom, F statistic and the significance level (p-value) of the influence of the equipment bag on the dependent variables: CPR quality and paramedics' work efficiency, effort and biomechanical loads.

Equipment bag		MANOVA			
		CPR quality	Work efficiency	Effort	Biomechanical loads
Medication bag	Df-num	20	12	12	12
	Df-den	14	17	17	14
	F	5.25	4.58	2.6	45
	p	**<0.05**	**<0.05**	**<0.05**	**<0.05**
Monitor-defibrillator	Df-num	20	12	12	12
	Df-den	14	17	17	14
	F	6.15	1.9	4.5	3.66
	p	**<0.05**	0.1	**<0.05**	**<0.05**
Air-way bag	Df-num	15	9	9	9
	Df-den	11	17	17	14
	F	3.4	2.38	0.6	3.5
	p	**<0.05**	0.06	0.76	**<0.05**
Oxygen tank	Df-num	25	15	15	15
	Df-den	17	17	17	14
	F	4.1	3.9	0.8	2.4
	p	**<0.05**	**<0.05**	0.6	**0.05**

equipment bags were positioned 50–90 cm from the paramedic. In such cases the paramedic did not change his/her position but preferred to change his/her posture, which resulted in awkward working postures. REBA has been for many years, and still is, one of the most popular ergonomics tools (Al Madani and Dababneh, 2016). Yet it suffers from a number of limitations. In particular, REBA is a subjective tool and therefore suffers from relativity high inter-rater variability (Kee and Karwowski, 2007). Further, the frequency and duration of tasks are not considered; therefore REBA is more appropriate for calculating peak biomechanical loads and less suitable for evaluating cumulative loading (Al Madani and Dababneh, 2016; Jones & Kumar, 2007).

As mentioned, both the peak compression forces and the REBA score provide information about the maximal loads during a task. Yet several studies suggest that the cumulative load is a risk factor for MSD (Coenen et al., 2013; Kumar, 1990; Gallagher and Schall, 2017). Paramedics may perform activities that involve equipment handling more than once during a shift, and in many cases, they maintain the awkward postures for up to 30 s (e.g., while extracting equipment from a bag). Therefore, it seems that the risk of MSD could be even higher than that predicted based on maximal loads. Thus future studies should consider cumulative load measures such as the cumulative lifting index (CULI; Garg and Kapellusch, 2016), the Lifting Fatigue Failure Tool (LiFFT; Gallagher et al., 2017), or the Distal Upper Extremity Tool (DUET; Gallagher et al., 2018).

4.4. Evaluation of work efficiency during CPR

The senior paramedic spent more time than the junior paramedic moving around the patient and changing positions. We believe this is because the senior paramedic executes most of the treatment activities (e.g., medication injections, electric shock). It was observed that in most cases, the paramedics changed position in order to reach a bag that was located far from them. Thus, positioning the relevant equipment in closer proximity to the senior paramedic would allow him/her to invest more time on patient treatment and less time on accessing the bags. Another explanation for the differences between the teammates could be that the senior paramedic moved more in order to avoid awkward postures while handling the bags and thus to reduce the biomechanical loads acting on his/her body.

In this study we assumed that time spent on position changes does not directly contribute to the CPR and therefore represents inefficiency on the part of the paramedics. Yet it is possible that in some cases the paramedics chose to change position in order to improve the CPR quality – a decision that might depend on the procedure being carried out, the paramedic's experience, and their role. In these cases, the measures in the current study might not be useful for evaluating the paramedics' work efficiency.

4.5. The effect of equipment bag position on CPR quality and paramedics' work efficiency, effort and biomechanical loads

The results of this study show that the positions of the equipment bags around the patient during out-of-hospital CPR affect CPR quality as well as paramedics' work efficiency, effort and biomechanical loads. There could be several explanations as to why CPR quality was affected by the positions of all four equipment bags. The first could be that the positions of the equipment bags had an effect on the paramedics' level of exertion, which in turn influenced their level of fatigue. Previous studies have shown that fatigue affects CPR quality (McDonald et al., 2013; Heidenreich et al., 2006). The second explanation could be related to the paramedic's position relative to the patient during CPR, which has also been found to influence CPR quality (Chi et al., 2008; Hong et al., 2014). Thus, it is possible that the positions of the equipment bags forced the paramedics to adopt a non-optimal position relative to the patient (e.g., too far, awkward posture), which in turn affected CPR quality.

The physiological effort was affected by the positions of the medication bag and the monitor. A possible explanation is that the positions of these bags might have had a strong influence on the number of lifts, pushes, pulls, steps, and position changes performed by the paramedics, all of which might have affected the paramedics' heart rate or perceived level of exertion. It is also possible that the positions of the medication bag and monitor influenced the exertion level since they were the two heaviest equipment bags, and load magnitude has been found to influence level of exertion (Dempsey et al., 2008; Taboun and Dutta, 1989; Garg et al., 1978).

Work efficiency was affected by the medication bag and oxygen tank positions. These were the two most handled (i.e., lifted, pushed and pulled) equipment bags. Furthermore, due to the small simulated room size (see Section 2.2), in some cases the medication bag and oxygen tank blocked the way for a paramedic to reach his/her desired position. Thus, the paramedic was forced to choose a longer route, which affected the number of steps and the time spent in position changes. Work efficiency could be important to the survival rate after cardiac arrest since it may affect the time interval before the first defibrillation shock or the first administration of epinephrine, which in turn have been found to affect the success rate of CPR (Brillhart et al., 2002; Andersen et al., 2016). It is also possible that non-efficient work may reduce the paramedics' level of focus, increase their mental load and result in errors (Holden et al., 2011; Karsh et al., 2006).

The biomechanical loads were affected by the positions of all four equipment bags. In most of the simulations, the paramedics positioned themselves in a similar location relative to the mannequin (i.e., one paramedic above the head and the second paramedic beside the chest). There were three types of poor positioning of the bags. First, when the paramedics positioned the equipment bags out of their reach, which forced them to lift, push or pull the bags more frequently than they would do otherwise in order to use them in close proximity to the patient. Second, positioning the equipment bags in too close proximity, thus forcing the paramedics to lift, push or pull the equipment bags in order to access the patient. Third, bag positions that were far from the paramedics, yet the paramedics could still reach the bags using awkward postures. These postures included increased trunk flexion, bending and twisting, elevated upper arms and neck twisting – all of which might result in increased risk of MSD. Yet in many cases the paramedics chose to handle the bags using these awkward postures rather than to move the bags closer to themselves or to change their own position to be closer to the bags.

4.6. Limitations

The equipment bags in this study are those used by paramedics in the MDA (the Israeli national emergency medical services). However, these bags, as well as the CPR procedure taught to paramedics in the MDA, are based on international guidelines and standards, and should be reasonably representative of most countries. Therefore, the results that illustrate the importance of bag positioning are likely to be valid for other jurisdictions. Secondly, this study focuses on the positions of equipment bags during out-of-hospital CPR as a result of cardiac arrest. Yet the results might be valid for other scenarios (e.g., trauma victims) in which the paramedics use the same equipment bags.

The back compression forces when lifting the bags were evaluated using the equation of Hoozemans et al. (2008), which consider only the lifted weight and the initial lifting height. Thus it does not consider variations in the subject anthropometrics (i.e., gender, height, weight), nor does it take account of the lifting technique (i.e., the degree of knee and trunk bending).

The paramedics' heart rate was evaluated using a Garmin 235 watch, which is a photoplethysmography-based monitor. Recent studies found this specific model and a similar one (Garmin 225) to result in accurate measures across different physical activities (Støve et al., 2019; Claes et al., 2017). Thus we believe that the use of such a device meets the need of our study. Yet it should be noted that the use of photoplethysmography-based monitors for predicting heart rate is not fully clinically accepted.

Finally, the MANOVA test was performed using the Lawley-Hotelling statistic, which was chosen out of a number of possible statistics (e.g., Pillai, Wilk's). While there is no one answer regarding which statistic to choose (Warne, 2014), it is possible that other statistics would result in different significance values.

4.7. Future work

Future work should examine different possible positions for the equipment bags around the patient, with the aim of producing guidelines regarding the optimal positions with respect to CPR quality, work efficiency, physiological effort and biomechanical loads. Secondly, the results of this study show that simulations of out-of-hospital CPR can exhibit a wide range of values for CPR quality measures. While investigation of the variability in CPR quality was not within the scope of the current study, future research could study the parameters that affect between- and within-subject variability during out-of-hospital CPR, as this has potential for improving CPR treatment. Lastly, the results of this study suggest that the influence of bag positioning on paramedics' performance and ergonomics should be investigated for additional work scenarios (e.g., treating trauma victims).

5. Conclusions

Currently, paramedics are not given any instructions or guidelines regarding where to position the bags around the patient during out-of-hospital CPR. Our results demonstrate that the initial positions of the equipment bags influence clinical measurements of CPR quality, as well as measures of the paramedics' work efficiency, effort and biomechanical loads. Furthermore, in some cases, due to the sub-optimal way in which the equipment bags are positioned, it seems that the paramedics waste time moving around the patient in order to reach their equipment. Finally, this study showed that paramedics often position themselves in postures that result in high risk of MSDs (according to REBA) and in spinal loads that exceed the maximum NIOSH threshold of 3400 N. These results highlight the need to consider the positioning and handling of the equipment bags during out-of-hospital CPR when seeking to improve paramedics' performance and reduce their risk of MSD.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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