The Importance of Physical Fitness In the Performance of Adequate Cardiopulmonary Resuscitation∗

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The aim of the present investigation was to evaluate the influence of the physical fitness of a cardiopulmonary resuscitation (CPR) provider on the performance of and physiologic response to CPR. To this end, comparisons were made of sedentary and physically active subjects in terms of CPR performance and physiologic variables. Two study groups were established: group P (n = 14), composed of sedentary, professional CPR rescuers (mean ± SD; age, 34 ± 6 years; VO₂ max, 32.5 ± 5.5 mL/kg/min), and group Ex (n = 14), composed of physically active, nonexperienced subjects (age, 34 ± 6 years; VO₂ max, 44.5 ± 5.5 mL/kg/min). Each subject was required to perform an 18-min CPR session, which involved manual external cardiac compressions (ECCs) on an electronic teaching mannequin following accepted standard CPR guidelines. Subjects’ gas exchange parameters and heart rates (HRs) were monitored throughout the trial. Variables indicating the adequacy of the ECCs (ECC depth and the percentage of incorrect compressions and hand placements) also were determined. Overall CPR performance was similar in both groups. The indicators of ECC adequacy fell within accepted limits (ie, an ECC depth between 38 and 51 mm). However, fatigue prevented four subjects from group P from completing the trial. In contrast, the physiologic responses to CPR differed between groups. The indicators of the intensity of effort during the trial, such as HR or percentage of maximum oxygen uptake (VO₂ max) were higher in group P subjects than group Ex subjects, respectively (HRs at the end of the trial, 139 ± 22 vs 115 ± 17 beats/min, p < 0.01; percentage of VO₂ max after 12 min of CPR, 46.7 ± 9.7% vs 37.2 ± 10.4%, p < 0.05). These results suggest that a certain level of physical fitness may be beneficial to CPR providers to ensure the adequacy of chest compressions performed during relatively long periods of cardiac arrest. (CHEST 1999; 115:158–164)

Key words: cardiopulmonary resuscitation; exercise; fitness.
Abbreviations: CPR = cardiopulmonary resuscitation; ECC = external cardiac compression; HR = heart rate; RER = respiratory exchange rate; Ve = minute ventilation; VO₂ = oxygen uptake; VO₂ max = maximum oxygen uptake; Vt = tidal volume

To date, the early performance of adequate chest (cardiac) compressions is a standard of care that

is considered to provide the optimal outcome in cardiopulmonary arrest.¹ Manual external cardiac compressions (ECCs) represent a simple and readily available cardiopulmonary resuscitation (CPR) technique that artificially produces sufficient cardiac output to maintain basal cardiac and neurologic activities until spontaneous circulation is restored by methods such as mechanical ventilation, defibrillation, or drug administration.² ³ However, despite its proven efficacy, manual ECC has disadvantages. For example, it is difficult for one person to deliver vigorous, manual ECCs for long periods, which
results in inadequate chest compressions that may be insufficient to provide the blood flow required to maintain critical organ function.\textsuperscript{4} Several authors have reported different methods to improve basic CPR (eg, variation of compression rate and abdominal binding).\textsuperscript{3,5,6} Furthermore, mechanical active compression-decompression CPR has been introduced in an attempt to improve the outcome of CPR after cardiac arrest.\textsuperscript{7} Little attention, however, has been focused on the fact that the fatigue of the CPR provider may result in inadequate compression.\textsuperscript{8}

On the other hand, numerous epidemiologic surveys suggest that adequate, regular exercise can maintain or improve fitness, preserve good health, and enhance the quality of life in comparison to a more sedentary style of life.\textsuperscript{9} Moreover, a number of studies have reported a potentially beneficial relationship between regular physical activity and several indicators of productivity in physically active employees.\textsuperscript{10} Consequently, it may be hypothesized that a high level of physical fitness could improve the efficacy of CPR. Although the data with which to evaluate the energetic cost of CPR are scarce, previous research suggests that such a procedure is physiologically demanding on subjects, including well-trained professionals. Indeed, blood lactate concentrations of approximately 3.0 mmol/L and heart rates (HRs) of approximately 130 beats/min have been reported recently in experienced professional CPR rescuers after a 30-min session of standard CPR.\textsuperscript{11}

The aim of the present investigation was to evaluate the influence of the CPR provider’s physical fitness on performance and physiologic variables during the CPR session. A comparison was made of the results obtained from two subject groups: sedentary, professional CPR rescuers; and physically active, nonexperienced subjects.

**Materials and Methods**

**Subjects**

Fourteen experienced, male, professional CPR rescuers (group P) from a mobile intensive care unit (Servicio Especial de Urgencias 061, Insalud, Madrid, Spain) with a mean (± SD) of 6 ± 2 years of experience (range, 2 to 11 years), and 14 male health professionals (physicians, physical therapists, and exercise physiologists) with no previous experience in CPR (group Ex) were selected as subjects for the study. The subjects in group P were sedentary and had not performed any regular, vigorous exercise during the preceding 2 years. In contrast, group Ex subjects were physically active and had followed an exercise program (3 to 5 sessions/wk, each consisting of 20 to 60 min of continuous activity such as running, cycling, or swimming) similar to that recommended by the American College of Sports Medicine to improve and maintain cardiorespiratory fitness in healthy adults.\textsuperscript{12}

The mean (± SD) age, height, and weight, respectively, of the subjects were as follows: group P, 34 ± 6 years, 171.7 ± 5.7 cm, and 80.4 ± 13.3 kg; group Ex, 34 ± 6 years, 176.3 ± 4.7 cm, and 77.3 ± 10.8 kg. Written informed consent was given prior to participation in the study in accordance with the institution’s (Escuela de Medicina del Deporte, Universidad Complutense de Madrid, Spain) guidelines for human subjects. Group Ex subjects received a brief training course in CPR prior to the trial.

**Maximal Exercise Test**

Before the initiation of the study protocol, all subjects performed an incremental exercise test to exhaustion to determine maximum oxygen uptake (V\textsubscript{O\textsubscript{2max}}) and ventilatory threshold (V\textsubscript{T}) using an automated breath-by-breath system (CPX; Medical Graphics; St. Paul, MN). The exercise test was performed on a cycle ergometer (Ergoline 900; Ergo-line; Barcelona, Spain) and consisted of a ramp protocol starting at 0 W. The workload was increased by 25 W/min, and the pedal frequency was kept constant at 60 to 80 revolutions/min. All exercise tests were terminated voluntarily by the subjects or when the established test termination criteria had been met.\textsuperscript{13} V\textsubscript{T} was determined using the criterion of an increase in both the ventilatory equivalent for oxygen and the end-tidal P\textsubscript{O\textsubscript{2}} with no increase in the ventilatory equivalent for carbon dioxide.\textsuperscript{14}

**CPR Performance**

Each of the subjects performed a standard CPR session on an electronic mannequin (Ambu Man-C; Ambu International; Copenhagen, Denmark). CPR included only manual ECCs since no ventilation was provided by the subjects. ECCs were conducted according to the following accepted guidelines: (1) subjects kneeled beside the mannequin; (2) a rate of 80 to 100 compressions/min was maintained; (3) a depth of 38 to 51 mm was maintained; and (4) a compression duration of 50% of the total compression cycle or “duty cycle,” which includes both the phases of chest compression and passive decompression of the chest wall, was maintained.\textsuperscript{15,16} Criteria for the termination of resuscitation were defined as the subject’s physical limit (physical exhaustion or pain) or > 18 min of resuscitation.

The mannequin was equipped with a real-time remote display that recorded the total number of compressions and the number of correct compressions. Compressions were recorded as correct if both depth and hand placement were in keeping with standard advanced cardiac life support guidelines.\textsuperscript{15}

A specially designed computer program (AmbuCPR; Ambu; Glostrup, Denmark) recorded each CPR session as a graphic, semiquantitative plot of compression depth vs time. The average values of the following variables were obtained from the mannequin after 6, 12, and 18 min of CPR: compression rate (ECCs/min); compression depth (mm); and compression adequacy, which was recorded as the percentage of complete cycles (compression duration of 50% of “duty cycle”) and as the percentage of incorrect hand placements. Subjects were not permitted to watch the computer monitor during performance. After completion of the test, each subject was informed about their own performance. They were instructed not to inform or share their experience with their peers.

**Physiologic Variables During CPR**

Subjects wore a mouthpiece connected to a small, lightweight (26 g) pneumotachograph (Prevent; Medical Graphics; St. Paul, MN) for the duration of the CPR session. A pneumotachograph enhances subject comfort by eliminating the need for cumber-
some breathing valves and hoses, and heavy headgear. Expired air was analyzed by an automated breath-by-breath system (CPX; Medical Graphics) in order to monitor gas exchange data continuously during each CPR session. Before each trial, the instruments were calibrated using a standard 3-L syringe and precision reference gases. Corrections were made for barometric pressure, ambient temperature, and humidity. HR (beats/min) was continuously monitored during the sessions as a modified 12-lead electrocardiographic tracing (EK56; Hellsteig; Freiburg, Germany). The 60-s average of the following physiologic parameters, monitored during the CPR session at 6, 12, and 18 min were determined: HR (beats/min); oxygen uptake (Vo2) in absolute and relative units, respectively (L/min and mL/kg/min); minute ventilation (Ve; L/min); and respiratory exchange ratio (RER). In addition, the percentage Vo2 max at 6, 12 and 18 min of resuscitation was also determined.

Capillary blood samples (50 μL) were taken from fingertips before and immediately after the termination of each session to determine blood lactate levels (mmol/L) using an automated lactate analyzer (YSI 23 L; Yellow Springs Instruments; Yellow Springs, OH).

Statistical Analysis

Data were analyzed using the SPSS 7.5 for Windows statistical package (SPSS Inc.; Chicago, IL). The Kolmogorov-Smirnov test17 was used to demonstrate a Gaussian distribution of data. A Student’s t test for unpaired data was used to compare physiologic variables between groups during the exercise test. Blood lactate levels were compared within and between groups using a Student’s t test for paired and unpaired data, respectively. In addition, the following comparisons of average physiologic and performance variables during the CPR session were performed: within groups at 6, 12, and 18 min using one-way repeated-measures analysis of variance; and between groups at 6, 12, and 18 min using one-way analysis of variance. When a significant F ratio was found, a Newman-Keuls post hoc analysis was performed to determine where the significant differences existed. A nonparametric test (Mann-Whitney) was used for data that did not show a normal distribution. The level of significance was set at 0.05. All data are expressed as the mean (± SD).

Results

Maximal Exercise Test

Physiologic data obtained in the maximal exercise test are shown in Table 1. Subjects in group Ex showed higher maximal and Vt values than those in group P.

CPR Performance

CPR Duration and Subject Assessment: There was no significant difference in the duration of CPR between groups, although a tendency toward a longer duration was observed in group Ex vs group P, respectively (1,080 ± 0 vs 979 ± 175 s). All the subjects in group Ex were able to complete the 18-min CPR session, whereas four subjects in group P stopped the session before 18 min. Reasons for early termination were pain in the upper extremity or in the vertebral column (n = 2) and dyspnea (n = 2). Consequently, the statistical comparison between groups at 18 min included only 10 subjects from group P.

Compression Rate: All the subjects were able to maintain an ECC rate of 80 to 100 compressions/min, which is in agreement with accepted guidelines for standard CPR.15,16

Compression Depth: No significant differences were found within groups during the trials (p > 0.05; Fig 1). Although average values were consistently lower in group Ex subjects throughout the tests (p < 0.001, p < 0.01, and p < 0.05 at 6, 12, and 18 min, respectively), the mean values fell within standard accepted limits (38 to 51 mm) in both groups.

Percentage of Incorrect Compression Cycles: No significant differences within or between groups were found (Fig 1).

Percentage of Incorrect Hand Placements: No significant differences within or between groups were found (Fig 1).

Physiologic Variables During CPR

Lactate Levels: Lactate levels significantly increased (p < 0.001) within the groups after CPR. There were no significant differences in pre- and post-CPR lactate levels between groups (Fig 2).

HR: Although the average values did not change in group Ex during the trial, the average HR increased in group P (p < 0.01) at 12 and 18 min during CPR with respect to values at 6 min (Fig 3). However, HR values were significantly lower in group Ex (p < 0.01) at each follow-up time.

Ventilation: No significant differences within or between groups were observed (Fig 3).

RER: In both groups, RER values were lower

Table 1—Maximal Exercise Test*

<table>
<thead>
<tr>
<th>Maximal values</th>
<th>Group Ex, n = 14</th>
<th>Group P, n = 14</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vo2 max, L/min</td>
<td>3.4 ± 0.6</td>
<td>2.6 ± 0.4</td>
<td>p &lt; 0.001</td>
</tr>
<tr>
<td>Ve max, mL/kg/min</td>
<td>44.5 ± 8.5</td>
<td>32.5 ± 5.5</td>
<td>p &lt; 0.001</td>
</tr>
<tr>
<td>Ve, L/min</td>
<td>144.0 ± 34.7</td>
<td>110.8 ± 25.2</td>
<td>p &lt; 0.001</td>
</tr>
<tr>
<td>HR, beats/min</td>
<td>183 ± 10</td>
<td>181 ± 12</td>
<td>NS</td>
</tr>
</tbody>
</table>

Values at Vt

| Vo2, L/min | 1.9 ± 0.4 | 1.4 ± 0.2 | p < 0.001 |
| Ve, L/min  | 43.97 ± 9.7 | 34.6 ± 5.7 | p < 0.001 |
| HR, beats/min | 131 ± 11 | 123 ± 11 | NS      |

*All values are expressed as mean (± SD).
†NS = no significant difference.
during the second part of the CPR session \( (p < 0.05) \) for 12 and 18 min vs 6 min; Fig 3). No significant differences between groups were detected.

\( \text{VO}_2 \): No significant differences were found within groups during the trial whether \( \text{VO}_2 \) was expressed in absolute or relative units (Fig 4). No significant differences were encountered between groups with the exception of higher \( \text{VO}_2 \) in group Ex than in group P at 18 min \( (p < 0.05) \).

**Percentage of \( \text{VO}_2 \)max:** There were no significant differences within groups (Fig 4). However, group P subjects tended to perform CPR at a higher percentage of \( \text{VO}_2 \)max than group Ex subjects. This was statistically significant at 12 min \( (p < 0.05) \).

**Discussion**

The main finding of this study was that, despite their lack of expertise, nonexperienced, physically fit subjects showed different physiologic responses than and comparable CPR performances to professional, sedentary subjects. The average values of CPR performance indicators such as the percentages of incorrect cycles and incorrect hand placements were similar in both groups. In addition, although ECC depth was consistently lower in group Ex at each follow-up time, the average value was still within standard accepted limits (38 to 51 mm).\(^{15,16}\) Furthermore, the duration of the trials tended to be longer in group Ex. In group Ex, each subject was able to complete the trial, whereas 4 of 14 experienced rescuers in group P showed signs of physical fatigue that forced them to stop ECCs before 18 min. It should be noted that in real situations a minimum of 30 min of CPR is often required.\(^{15,16}\) Moreover, since hypothermia confers protection against the effects of hypoxia, resuscitation efforts in hypothermic patients should be continued for much longer.\(^{16}\)

The physiologic responses of the subjects differed considerably between groups. Group P subjects showed significantly higher HR values throughout the trial and also showed a tendency to provide compressions at a higher percentage of \( \text{VO}_2 \)max. These observations suggest that physical fitness has a significant effect on the physiologic response of resuscitation providers. Physically fit individuals can provide ECCs at a lower intensity of exercise and, therefore, have a higher resistance to fatigue. Absolute \( \text{VO}_2 \) tended to be lower in group P, perhaps suggesting a greater economy of movement during the resuscitation maneuvers, which in turn may be attributed to previous experience (5 ± 3 years). Alternatively, these findings simply may be attributed to the fact that values of \( \text{VO}_2 \)max were considerably lower in group P. However, it should be kept in mind that these subjects performed ECCs at a higher percentage of \( \text{VO}_2 \)max (i.e., at a higher intensity of effort). Finally, blood lactate levels significantly increased in both groups after CPR, but no signific-

\[\text{Figure 1. ECC adequacy: compression depth, percentage of incorrect cycles, and percentage of incorrect hand placements.} \]

\[\delta = p < 0.001, p < 0.01, \text{and } p < 0.05 \text{ for group Ex vs group P at 6, 12, and 18 min, respectively.} \]
significant differences were found between groups. This may be related to the fact that the majority of group Ex subjects had undergone exercise that mainly involved the lower extremities (walking, running, cycling, etc.), whereas ECC principally involves the trunk and upper body muscles.

Despite the tendency of previous resuscitation research to focus on advanced life support measures, the provision of adequate ECCs is still the standard care procedure for victims of cardiac arrest. In this regard, the present study has evaluated the effects of aerobic training on several indicators of ECC performance (such as the rescuer’s time to fatigue and the adequacy of compressions) and on the physiologic responses to such activity. Although other authors have reported the physiologic responses of experienced, professional CPR rescuers (a mean Vo2 max of approximately 45 mL/kg/min) to a session of standard CPR that lasted approximately 30 min, no data concerning their aerobic training was provided. In the present investigation, a group of physically active individuals with relatively high Vo2 max values (approximately 45 mL/kg/min), in comparison with standard values for healthy adults of the same age group (30 to 39 years),18 was selected. In contrast, the Vo2 max of group P subjects was moderate and was considerably lower (approximately 32 mL/kg/min) than that of group Ex subjects. This contrast permitted evaluation of the influence of physical fitness on the physiologic responses of CPR providers.

The present findings are in agreement with the suggestions of Baubin et al11 and show the need for at least a minimum level of physical conditioning in CPR providers. Such a conclusion is supported by the fact that physically fit individuals with no previous experience in resuscitation maneuvers were as effective as sedentary, professional rescuers in performing chest compressions. The practice of ECC is a moderately intense activity that requires a certain level of physical fitness, as shown by the increase in blood lactate levels in both subject groups. Furthermore, the metabolic cost of CPR was not negligible (a Vo2 of approximately 14 mL/kg/min, or 4 metabolic equivalents, in group P) and corresponds to that of activities such as recreational cycling or swimming. These are commonly perceived as “moderately” intense by healthy adults.19 In addition, during situations of actual cardiac arrest, ECCs should not be interrupted at all during resuscitation since cardiac output increases cumulatively during the first compressions.20 Other authors also have suggested that there is little margin of error in the provision of adequate critical organ perfusion by ECC.21–23 Furthermore, it has been reported recently that trained personnel reach a state of physical fatigue relatively rapidly, at which time the compressions probably become inadequate to ensure vital organ perfusion.8 Moreover, CPR providers might not be able to recognize their own fatigue or its effects on ECC performance.3,8

On the other hand, the limits of this investigation include the fact that CPR was performed on a mannequin under almost ideal laboratory conditions.

![Figure 2: Blood lactate levels. * = p < 0.001 in both groups for pre- vs post-CPR.](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21894/ on 06/21/2017)
Under “real” conditions (ie, during an actual arrest), rescuers probably achieve better ECC performance because chest compressions are easier to perform in human beings and there is a sense of urgency.8

In conclusion, the findings of this study suggest the possibility of including a fitness program (ie, light to moderate aerobic exercise) for CPR providers as part of their general training. On the other hand, CPR training is not limited to paramedic personnel. In fact, in Western societies, the survival rate of victims of cardiac arrest largely depends on the intervention of trained bystanders in initiating and maintaining CPR before paramedic personnel arrive.24 The fact that nonexperienced, physically fit subjects and professional, sedentary subjects showed comparable CPR performances, despite contrasting

**Figure 3.** Physiologic responses during ECC: HR, VE, and RER. 

* = p < 0.01 for 12 and 18 min vs 6 min in group P; § = p < 0.01 for group Ex vs group P; and ** = p < 0.05 for 12 and 18 min vs 6 min.

**Figure 4.** Physiologic responses during ECC: VO₂ and effort intensity (percentage of VO₂max). § = group Ex vs group P at 18 min, p < 0.05; and § = group Ex vs group P at 12 min, p < 0.05.
physiologic responses, strengthens the notion that physical fitness can have a positive impact on resuscitation efforts.

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