Effect of Wrist Restraint on Maximal Exercise Capacity in Healthy Volunteers

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Abstract: Each year, reports occur of deaths in individuals, while struggling against physical restraint. The mechanism of these deaths remains unclear. This study aimed to determine the effect of wrist restraint on cardiorespiratory function during maximal exercise. Twelve healthy volunteers underwent 3 incremental maximal exercise tests on a cycle ergometer. In a randomized order, they exercised while unrestrained, with the wrists tied in front of the body or wrists tied behind the back. The primary outcome measures were the number of minutes exercised in each position and heart rate and whole blood lactate level for each stage and on reaching maximum exercise capacity. The mean exercise duration was 19 minutes 6 seconds unrestrained (95% confidence interval [CI] 16 minutes 52 seconds to 20 minutes 57 seconds), 18 minutes 51 seconds (95% CI 17 minutes 51 seconds to 20 minutes 50 seconds) with arms restrained in front and 16 minutes 51 seconds (95% CI 14 minutes 6 seconds to 19 minutes 20 seconds) with the arms restrained behind the body ($P = 0.16$). There was no significant difference in heart rate or lactate measurements. It is probable that other factors make a more important contribution than wrist restraint behind the body to cardiorespiratory compromise in a struggling and fatigued individual.

Key Words: restraint, physical, exercise test, death, sudden

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Physical restraint of an individual by healthcare workers or police officers is sometimes necessary during the course of duties, in individuals who have become violent or aggressive and are a danger to themselves and others. However, a small number of people die each year during restraint situations.[1–5] The mechanism of these deaths remains unclear and is a source of considerable debate.

The prone body position is the position mostly associated with deaths, particularly if the wrists have been restrained behind the back. The most extreme example of this is the "hogtied" or "hobble" position, where the wrists are secured behind the back with ankles bound together and tied to the wrists. Previous authors[6] suggest that hyperextension of the shoulders in this position could restrict movement of the chest wall, thus contributing to cardiorespiratory impairment in restraint situations. In addition to body positioning, a familiar characteristic of a person dying in restraint situations is one of extreme exhaustion due to excessive exertion and continual struggling against restraint right up until the point of collapse. Many of these individuals have been shown to be suffering with agitated delirium. This is a condition characterized by acute confusion, hyperthermia, irrational and often violent behavior, and an apparent unresponsiveness to pain or fatigue. Agitated delirium has a high mortality rate, which arises either secondary to an underlying psychiatric condition or to the influence of stimulant drugs, predominantly cocaine.[2,5,7]

Pathophysiological studies to date have examined the cardiorespiratory effects of positional restraint[8–10] but have not examined such effects in subjects who are maximally fatigued by physical exertion. Similarly, there have been no studies looking at the effect of restraint during dynamic exercise.

We postulate that when an individual is restrained with hands behind their back, the shoulders will be pulled in a superior and posterior direction, in effect hyperexpanding the chest wall and limiting chest-wall movement in both the inspiratory and expiratory phases of respiration. This may reduce the compliance of the chest wall, resulting in an increase in the work of breathing. It is known that increasing oxygen requirements by the respiratory muscles at maximal exercise leads to vasoconstriction within the locomotor muscles.[11] If the work of breathing is increased, then by this mechanism we would expect a reduction in exercise capacity.

This study aims to determine the effect that wrist restraint has on an individual's cardiorespiratory function and maximal exercise capacity. The hypothesis being tested is that wrist restraint behind the body will limit maximal exer-

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cise capacity and compromise cardiorespiratory function to a greater degree than individuals exercising with wrists restrained in front of the body or unrestrained.

Methodology

We conducted a randomized crossover experimental study with local ethics committee approval. Following informed consent, 12 healthy male volunteers, aged 18–35 years, were recruited. Each volunteer underwent an initial screening of their health. A clinical history was taken, including how much exercise was taken weekly, followed by a general examination. The following investigations were then undertaken: full blood counts, creatinine and electrolytes, and a resting electrocardiogram (ECG). Pulmonary function was tested in accordance with the American Thoracic Society criteria, including reproducibility within 5% variability on 3 repeated measurements.[12] The subjects' urine underwent toxicological screening by means of an immunoassay (SureStep Drug Screen Card). Subjects were excluded if they had any of the following: underlying or suspected cardiorespiratory disease, including asthma, a family history of hypertrophic obstructive cardiomyopathy or sudden death under 50 years age, or any abnormalities found during the testing listed above.

Testing took place in a laboratory fulfilling the guidelines for clinical exercise testing laboratories set out in the American Heart Association Medical/Scientific statement.[13] Exercise took place on a cycle ergometer (Siemens Ergomed 740). Subjects exercised in the following positions: unrestrained (group U), restrained with wrists tied in front of the body (group F), restrained with wrists tied behind the body (group B). Subjects exercised in all 3 positions in a randomized order, with at least 3 days between testing. Opaque sealed envelopes were used to establish randomization. Handcuffs were supplied by the London Metropolitan Police force, and a police inspector responsible for police training provided a training session in application and wrist positioning. Pilot studies revealed that subjects were discontinuing their exercise test due to wrist discomfort and the onset of paresthesias in the distribution of the superficial radial nerve, and so the handcuffs were substituted for soft-material restraints. The wrist positioning remained identical and was ensured by applying the handcuffs first, which were then removed once the correct wrist positioning had been confirmed.

Subjects began exercising at 50 W, increasing in 50-W increments at 3-minute intervals until they felt unable to continue. A standard 12-lead ECG, noninvasive blood pressure, and pre-exercise earlobe lactate sample were recorded initially. Subjects had continuous recording of heart rate via a 12-lead ECG tracing. During the second minute, blood pressure was recorded, and in the third minute the heart rate and Borg scale rating were recorded and a blood lactate sample from the earlobe was taken. A final lactate sample was taken on termination of exercise, and the subject was asked to give their reason for terminating the test. The primary outcome measures were the number of minutes exercised in each position and heart rate and whole-blood lactate level for each stage and on reaching maximum exercise capacity (within 1 minute). The Borg rating of perceived exertion[14] at each stage was recorded as a secondary outcome measure. Lactate analysis was measured using an Analox GL5 analyzer.

Statistical analysis was undertaken using a computerized statistical program (SSPS 11.0.0). A one-way ANOVA with repeated measures was used to determine differences in mean exercise time and heart rate and blood lactate at each stage of exercise. A probability value of less than 0.05 was considered statistically significant.

RESULTS

The mean age of volunteers was 25 years (S.D 3.3), with a mean body mass index of 25.5 kg/m^2 (SD 3.0). The mean exercise duration was 19 minutes 6 seconds unrestrained (95% confidence interval [CI] 16 minutes 52 seconds to 20 minutes 57 seconds), 18 minutes 51 seconds (95% CI 17 minutes 51 seconds to 20 minutes 50 seconds) with arms restrained in front, and 16 minutes 51 seconds (95% CI 14 minutes 6 seconds to 19 minutes 20 seconds) with the arms restrained behind the body ($P = 0.16$). See Figure 1.

Maximal heart rate was achieved in 6 of the unrestrained group (U), 7 of the group with arms restrained in front (F) and 4 of group with the arms restrained behind the body (B). Peak lactate measurements >8 mmol/L were obtained in 6 group U subjects, 4 group F subjects, and 5 group B subjects. The heart rate response to incremental exercise in each group is shown in Figure 2. The first 5 stages are

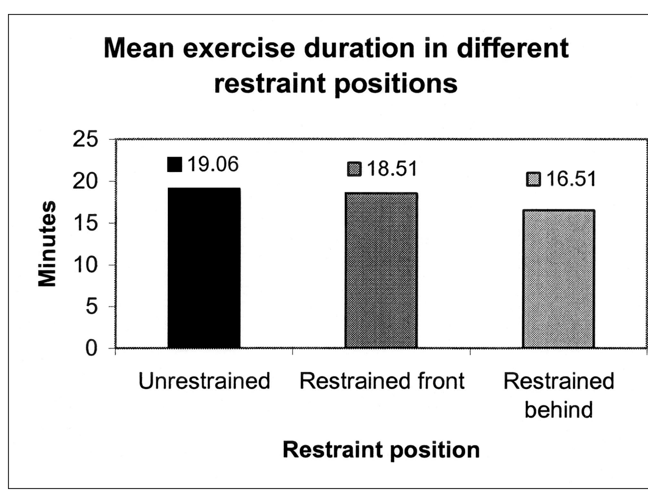

FIGURE 1. Mean exercise duration in the different restraint positions.

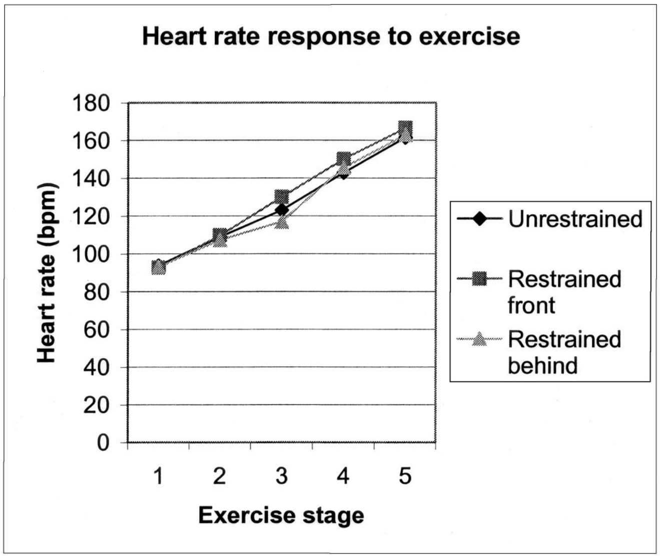

FIGURE 2. Heart rate response to incremental exercise.

compared as in the latter stages numbers become small. The peak lactate taken at termination of exercise was as follows: group U 7.73 mmol/L, group F 7.78 mmol/L, group B 7.69 mmol/L ($P = 0.99$). The lactate measurements during the first 5 stages are shown in Figure 3. Again, the first 5 stages are compared as in the latter stages, numbers became small particularly in the restrained groups. The Borg rating of perceived exertion showed no statistical difference at any stage. All subjects reported leg-muscle fatigue as the reason for discontinuing exercise.

DISCUSSION

This study assessed the effect of wrist restraint on exercise capacity in healthy men. It has been postulated that the action of restraining individuals' wrists behind their backs leading to hyperextension of the shoulders could lead to cardiorespiratory compromise. Additionally, during maximal exercise, the respiratory and limb muscles are in competition for blood flow.[11] As the work of breathing increases with exertion this results in lower-limb vasoconstriction and hence decreased blood flow to those muscles. We postulated that when the wrists are restrained behind the back, a reduced exercise capacity would result. This would imply that the restraint position increased the work of breathing, thus leading to an earlier decrease in blood flow to the legs.

Previous experimental studies have found measurable physiological changes in subjects restrained in a prone position with the wrists restrained behind the back. The first study of restraint positioning[8] examined the effects of the hogtie position versus a sitting position in 10 volunteers following 2 short exercise periods. The mean time for heart rate recovery was 0.96 minutes in the hogtie position and 0.56 minutes while seated ($P < 0.05$). Oxygen saturation (measured by ear-probe oximeter) was also slower to recover to pre-exercise levels in the hogtied patients. However, oxygen saturation was found to fall during exercise also. It is now well established that this does not occur, particularly at submaximal levels of exercise, and these findings are more likely to represent measurement error. The differences in heart rate were also not striking and clinically of little consequence in healthy individuals.

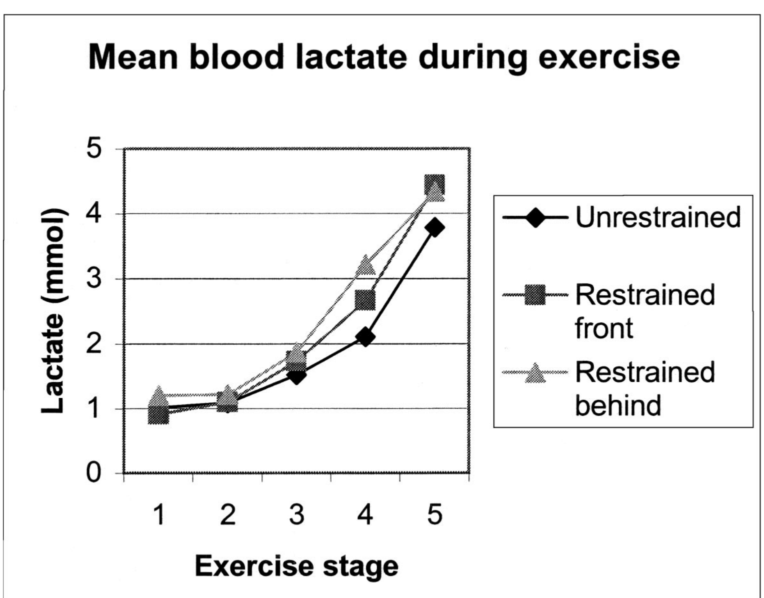

FIGURE 3. Mean blood lactate during exercise in the different restraint positions.

Chan et al[9] found more convincing differences in the effects of pulmonary function in subjects restrained. They measured pulmonary function, arterial blood gases, and oxygen saturation in 15 volunteers who were seated, supine, prone, and hogtied in a random order. Pulmonary function testing was then repeated in the hogtied and seated positions following a period of submaximal exercise. At rest, a statistically significant ($P < 0.01$) reduction in FEV_1 (forced expiratory volume in 1 second), FVC (forced vital capacity), and maximal voluntary ventilation was found in the restraint position when compared with sitting with a progressive reduction in ventilatory capacity from supine to prone to hogtied positions. Arterial oxygenation or carbon dioxide measurements did not change in any position. The exercise phase of the study consisted of two 4-minute periods on a cycle ergometer at 175 W. Following the first period of exercise, subjects were seated for 15 minutes, and following the second period, were hogtied. In both groups, FEV_1 increased postexercise and the FVC also increased in the restraint group. PO_2 measurements increased with exercise and showed no difference between groups.

Cardiovascular effects of hobble restraint have also been evaluated. Roeggla et al[10] compared hobble restraint in the prone and upright position at rest and found significant differences in cardiac output, heart rate, and systolic blood pressure. Cardiac output, measured by a noninvasive technique (Portapres), showed a reduction by 37% (5.35l to 3.35l) in the prone position. Heart rate and systolic blood pressure fell by 21% and 32%, respectively, in the prone position. Pulmonary function also showed a significant decline. The FEV_1 fell by 41% and the FVC by 39% in the prone position. No change was seen in oxygen saturation. The numbers in this study, however, were small ($n = 6$).

No previous study has exerted subjects maximally in a controlled manner prior to restraint positioning. While it is practically impossible both from the technical and safety aspect to maximally exercise an individual in a prone restraint position, we aimed to examine a single aspect of the restraint position (ie, wrist restraint during maximal exercise). This study has limitations similar to those encountered previously in the literature. The subject population included healthy males aged between 18 and 35 years, all of whom were screened carefully for the presence of underlying cardiac disease or illicit drug use and many of whom undertook regular physical exercise. While recognizing that females also need to be included in further research, male subjects were recruited as they currently represent the majority of restraint-related deaths.

In this study, we did not demonstrate any statistically significant difference in terms of time exercised, heart rate, or lactate response at each exercise stage in individuals with their wrists restrained behind the back when compared with no restraint or wrists restrained in front of the body. We conclude that it is unlikely that wrist restraint behind the body contributes substantially to cardiorespiratory compromise in a fatigued restrained individual who remains erect. However, when deaths actually occur in restraint situations, other risk factors are invariably present, including excited delirium, obesity,[1,7,15] stimulant drug use, and prone body positioning. Deaths will continue to occur when a critical combination of factors is present. Further studies are needed to fully elucidate the contribution each has to play in the demise of the individual.

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