

EFFECT OF TRAINING ON PHYSICAL CAPACITY AND PHYSICAL STRAIN IN PERSONS WITH TETRAPLEGIA

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ABSTRACT. The effects of quad rugby training on physical capacity and physical strain during standardized activities of daily living were investigated in 9 trained (A) and 5 untrained quad rugby players (B), and 7 inactive persons with tetraplegia (C) at 0, 3 and 6 months after the start of a quad rugby training program (1.5 h.wk⁻¹). Physical capacity was measured as maximal isometric strength, peak power output (PO_{peak}) and peak oxygen uptake (VO_{2peak}) on a stationary wheelchair ergometer. Physical strain was expressed as a percentage of heart-rate reserve. No measurable training effects could be observed for PO_{peak}, VO_{2peak} and physical strain. A significant rise in maximal isometric strength was found in group B after 3 and 6 months of training, whereas no significant changes were found in groups A and C. The results suggest that a higher training frequency and/or intensity may be needed to gain significant training effects for PO_{peak} and VO_{2peak}.

Key words: activities of daily living, heart-rate reserve, maximal isometric strength, maximal power output, peak oxygen uptake, tetraplegia, training.

INTRODUCTION

Individuals with spinal cord injuries (SCI) depend on a reduced muscle mass for locomotion. This may lead, in combination with a sedentary lifestyle, to a poor physical capacity (PC). Previous studies investigating the PC of persons with SCI have indeed reported very low levels of PC (3, 9, 11). Furthermore, as a result of a limited arm function, PC proved to be dramatically lower in persons with tetraplegia compared with persons with paraplegia and able-bodied persons (3, 6, 11). The relatively low PC

of persons with tetraplegia was found to be associated with high peak levels of physical strain (PS) during activities of daily living (ADL), such as wheelchair propulsion, making transfers, or ascending a ramp (12). Nevertheless, overall PS during daily life was found to be insufficient in magnitude and duration to maintain or improve PC, for both persons with tetraplegia and paraplegia (8, 13). It has been indicated that, owing to both the high physical strain in daily life and the enforced sedentary lifestyle, persons with SCI can end up in a debilitating cycle, leading to a further decline of PC (9). Therefore, it has been suggested that physical activity of sufficient intensity and duration, such as sport participation, may be a prerequisite to maintain or improve PC in persons with SCI (6, 9, 16), and thus reduce physical strain in daily life. This seems to apply in particular to persons with tetraplegia, owing to their extremely low PC.

Previous training studies in which regular training programs were evaluated, have demonstrated the possibilities of improving cardiovascular fitness in persons with tetraplegia (2, 4, 7, 14), whereas others found no such improvements (10). However, data are scarce, and most studies are performed under lab-training conditions which are not very applicable to the daily life situation of the general SCI population. The recent introduction of quad rugby (wheelchair rugby), a new team sport for persons with tetraplegia, has given these persons an opportunity to participate in a team sport. Playing quad rugby may have the potential to improve physical fitness. Therefore, the purpose of the present study was to evaluate the effect of quad rugby training on the PC and PS during standardized ADL in persons with tetraplegia. A trained and untrained (recently started) quad rugby team, as well as a control group of inactive persons with tetraplegia, was therefore followed during a period of 6 months.

MATERIALS AND METHODS

Subjects and testing procedure

Twenty-four individuals with a cervical spinal cord lesion, (C4/5 to C8) took part in this study after having given written informed consent. The subjects were divided in three groups: 9 trained quad rugby players who were active in sport for at least two years (group A), 6 untrained, recently started, quad rugby players (group B), and a control group of 9 inactive persons with tetraplegia (group C). Group A, all male, included 4 subjects with incomplete lesions (ASIA Impairment Scale [5]: D [$n = 3$] and C). All subjects in group B (5 males, 1 female) had complete lesions. In group C, 7 subjects were male with complete lesions, and 2 subjects were female, both with an incomplete lesion (ASIA Impairment Scale: B and D).

Tests were performed on three occasions: the first test (t1) was performed at the moment that group B started the quad rugby training, the second and third tests were performed after 3 months (t2) and 6 months (t3), respectively. Group C was tested at t1 and t3 only. One subject from group B, and 2 subjects from group C dropped out because of illness or injury. On each occasion subjects completed a questionnaire to obtain personal, health and medical data. Body mass was measured in a sitting position on a hospital scale. Characteristics of the 21 subjects who completed the training program are listed in Table I. One subject in group A was unable to complete the ergometer tests at t3 because of an elbow injury. Not all subjects were able to perform all standardized ADL tasks on all occasions, resulting in a varying number of subjects per task. Of the 21 subjects who completed all the tests, 9 subjects suffered from serious illness or injury (4 subjects in group A, 2 in group B and 3 in group C) at some stage during the 6-month period. Urinary tract infections ($n = 4$) and musculoskeletal problems ($n = 3$) were the most common complaints.

All subjects were asked to consume a light meal and refrain from smoking, drinking coffee and alcohol, at least two hours prior to testing. To avoid autonomic dysreflexia during the tests, subjects were asked to void directly before testing.

Physical capacity

An isometric strength test and a maximal exercise test were carried out on a computer-controlled, stationary wheelchair ergometer (15), which allowed for direct measurements of torques applied on the rim as well as resultant velocity of the wheels, for the left and right side separately. The wheel and handrim radii were 0.31 and 0.26 m, respectively. The ergometer was individually adjusted: seat height was standardized at 70° elbow flexion (0° defined as full extension) with the subject's

hands on the top of the rim, and the acromion directly above the wheel axle. Rear wheel camber was set at 4°. Seat angle and back-rest angle were set at 5° to the horizontal, and 15° to the vertical axis, respectively.

Isometric strength test. To measure maximal strength, an isometric test was performed on the ergometer, consisting of 5 seconds' maximal force exertion of both arms, with the hands at top dead center of the blocked rims. Three trials were performed with 2 minutes' rest between the trials. Torque was sampled with a frequency of 50 Hz. Effective isometric force (F [N]) was calculated according to:

$$F = M \cdot r_r^{-1} \text{ (N)}$$

where M (Nm) is the torque and r_r (m) is the rim radius.

Maximal isometric strength (Fiso [N]) was defined as the highest mean force (averaged over left and right arms) over 3 seconds. The highest value of three trials was used for further analyses.

Maximal exercise test. Peak power output (PO_{peak} [W]) and peak oxygen uptake (VO_{2peak} [l·min⁻¹]) were determined in a maximal exercise test, consisting of 1-minute exercise bouts at a constant velocity of 0.83 m·s⁻¹ or 0.56 m·s⁻¹. Visual feedback on the velocity was provided, and subjects were instructed to maintain the required velocity at a constant level. To set the appropriate resistance level, PO_{peak} was initially estimated, using maximal isometric strength and regression equations established by Janssen et al. (11) for the relationship between maximal isometric strength and PO_{peak} in persons with SCI (PO_{peak} [W·kg⁻¹] = 0.34 · Fiso [N·kg⁻¹] - 0.02). Starting with a resistance level of 10% of the estimated PO_{peak}, resistance was increased each minute in equal steps of 10% of the estimated PO_{peak}. The test was terminated when the subject could no longer maintain the imposed velocity owing to exhaustion. Verbal encouragement was provided during the test. Torque and velocity of the wheels were measured (during 10 seconds) each 1-minute exercise bout, with a sample frequency of 50 Hz.

Power output (PO [W]) was calculated according to:

$$PO = M \cdot \omega \text{ (W)}$$

where ω (rad·s⁻¹) is the angular velocity.

For each 1-minute exercise bout, mean power output (sum of left and right arm) was calculated over 10 seconds. The highest mean power output that occurred during the test was defined as PO_{peak}.

Table I. Mean and standard deviation (in parentheses) of subject characteristics for each group. No significant differences were found between groups

	Trained group ($n = 9$)	Untrained group ($n = 5$)	Control group ($n = 7$)
Age (years)	30.6 (12.7)	26.0 (7.1)	39.6 (8.4)
Body mass (kg)	72.7 (16.3)	73.0 (25.9)	73.9 (20.4)
Time since injury (years)	7.4 (9.9)	6.3 (4.0)	5.6 (5.3)
International quad rugby classification	2.06 (1.21)	0.90 (0.42)	–

Oxygen uptake was measured continuously during the test using an Oxycon Ox4 (Mijnhardt, The Netherlands). Calibration was performed prior to each test with reference gases. $\dot{V}O_{2peak}$ was defined as the highest value recorded during the test, averaged over 60 seconds. Heart rate (HR [$\text{b}\cdot\text{min}^{-1}$]) was monitored with a Polar Sport Tester (Polar Electro Incorporation, Finland) sampling with a 5-second interval period. HRpeak was defined as the highest HR found during the whole testing period (training and matches included).

Physical strain during ADL

To measure PS during ADL, the following tasks were performed in successive order: ascending a ramp with an inclination of 3.5° and a length of 6 m, opening and closing a sliding door and washing hands. To assess PS during wheelchair propulsion, each subject performed an additional test on the wheelchair ergometer (same configuration as described above), in which wheelchair propulsion against a slope of 0.5° was simulated. Test duration was 3 minutes, with a constant velocity of $0.83 \text{ m}\cdot\text{s}^{-1}$. Rolling resistance coefficient was set at 0.01. The individual body mass of the subject, with 20 kg added for the wheelchair, was simulated.

During the tasks, HR was monitored with a Polar Sport Tester (see above), sampling with a 5-second interval period. For each subject, the individual heart-rate reserve (HRR [$\text{b}\cdot\text{min}^{-1}$]) was calculated, which is defined as the range between the resting HR (HR_{rest}, measured in sitting position) and the HR_{peak}. To estimate PS during a task, the highest HR provoked by the task (HR_{task}) minus the HR_{rest} was expressed as percentage of the heart-rate reserve (%HRR [%]), according to:

$$\frac{HR_{\text{task}} - HR_{\text{rest}}}{HR_{\text{peak}} - HR_{\text{rest}}} * 100 (\%)$$

Quad rugby training program

During the 6-month period, all subjects of groups A and B participated in a quad rugby training program. Training sessions were performed once a week, and each session lasted 1.5 to 2 hours.

The training program included wheelchair endurance training, arm strength training, and a training to improve ball skills and wheelchair handling. Test matches were played regularly during the training sessions. Owing to illness or injury, some subjects were unable to participate in all training sessions. As a consequence, the total number of followed training sessions varied between subjects from 19 to 25 during the 6-month period. In addition, both groups played two competition matches each month. These matches were played on the same day, and each match lasted 90 minutes.

To determine exercise intensity of the training and competition matches, HR was measured using a Polar Sport Tester (see above), sampling with a 5-second interval period. Twenty-five HR recordings were made (in 14 subjects; 9 subjects of group A and 5 subjects of group B) during six quad rugby training sessions. During four different quad rugby competition matches, 18 HR recordings were made (in 12 subjects; 8 subjects of group A and 4 subjects of group B). Total time spent at an intensity of more than 60 %HRR was calculated for each group.

Statistics

A non-parametric test for two dependent samples (Wilcoxon matched-pairs signed-ranks test) was applied to detect significant differences in PC and PS parameters, between t1, t2 and

t3. A Kruskal-Wallis one-way ANOVA was used to establish differences in subject characteristics, and to determine significant differences between groups for changes in PC (ΔFiso , ΔPOpeak and ΔVO_{2peak}) and PS ($\Delta\%\text{HRR}$). A non-parametric test for two independent samples (Mann-Whitney U test) was applied to determine significant differences between group A and group B for exercise intensity of the quad rugby training and matches. Results were considered significant at $p < 0.05$.

RESULTS

Physical capacity

Results for maximal isometric strength, POpeak and $\dot{V}O_{2peak}$ at t1, t2 and t3 are listed in Table II. No significant within-group differences were found between t1, t2 and t3 for POpeak and $\dot{V}O_{2peak}$. Maximal isometric strength was significantly higher in group B at t2 ($116 \pm 80 \text{ N}$) and t3 ($107 \pm 70 \text{ N}$), compared with t1 ($92 \pm 65 \text{ N}$; $p < 0.05$), whereas in groups A and C no significant changes were found. No significant differences were found when ΔFiso , ΔPOpeak and ΔVO_{2peak} were compared between groups (see Table II).

Physical strain during ADL

Mean HRR for the total group showed no significant differences between t1 ($72.4 \pm 17.3 [\text{b}\cdot\text{min}^{-1}]$), t2 ($75.6 \pm 19.2 [\text{b}\cdot\text{min}^{-1}]$, for group A and B only) and t3 ($72.0 \pm 18.4 [\text{b}\cdot\text{min}^{-1}]$). The results for PS during standardized ADL are presented in Table III. PS showed no significant differences within groups over time. One subject of group B was unable to ascend the ramp at t1 and t2, although he was able to do so at t3. No significant differences could be detected between groups for $\Delta\%\text{HRR}$.

Exercise intensity during training and matches

Table IV shows the mean exercise intensity for groups A and B, expressed as time trained or played above 60 %HRR, and it is given both in minutes and in percentage of the total training or playing time. Group B showed a significantly higher exercise intensity during the training sessions ($42 \pm 15 \text{ min}$), compared with group A ($21 \pm 12 \text{ min}$; $p < 0.05$). No significant differences in exercise intensity of the matches were observed between groups A and B.

DISCUSSION

Up until now a number of lab-training studies have

reported improvements in physical fitness in persons with tetraplegia after training (2, 4, 7, 14). In the present study, however, a significant effect of a regular but non-controlled quad rugby training program could only be established for maximal isometric strength, whereas VO_2 peak, PO_{peak} and PS during standardized ADL showed no significant improvement. Moreover, the lack of significance between groups for ΔF_{iso} indicates that maximal isometric strength in group B did not significantly improve in comparison with the control group (group C).

Subjects

The small number of subjects and the heterogeneity of the experimental groups may have influenced the statistical analysis. These problems were also mentioned in previous studies (10, 14) and seem to be a recurrent problem in testing persons with tetraplegia. The high incidence of illness and injuries reduced the already small initial number of subjects, and, moreover, may have influenced the training effects in a negative way. The large number of serious health complaints reflects the vulnerability of persons with tetraplegia.

Physical capacity and physical strain during ADL

The extremely low values for PC (F_{iso} : 117 ± 66 N, PO_{peak} : 21 ± 13 W, VO_2 peak: 0.85 ± 0.42 l·min⁻¹, for

the total group at t1) and the high values for PS are in agreement with previous reports on persons with tetraplegia (6, 12). Tables II and III show that PC was lower, and PS was higher in group A, in comparison with groups B and C. Since groups could not be matched according to lesion level and completeness of the lesion, these differences in PC and PS can be explained by training status, as well as by differences in level and incompleteness of the lesion.

Training program

Training frequency and/or intensity of the present training program were probably not of sufficient magnitude to realize a training effect. Obviously, the training frequency of once a week in the current study was lower than in previous studies; successful training studies all used frequencies of at least 3 times per week (2, 4, 7, 14). Therefore, the low training frequency is the most likely explanation for the limited training effect observed here. However, the initial level of fitness can influence the results of a training program, and may therefore have influenced the results of the present study. Some remarkable individual improvements found in the current study indicate that a training effect (with the current training program) is likely to be expected for at least a limited number of subjects.

Since the current study investigated subjects who participated in team sport training, training intensity was non-controlled and could therefore have varied

Table II. Results for parameters of physical capacity for each group; maximal isometric arm strength (F_{iso}), peak power output (PO_{peak}) and peak oxygen uptake (VO_2 peak). Mean and standard deviations (in parentheses) are given

	t1	t2	t3
Trained group ($n = 8$)			
F_{iso} (N)	129.2 (68.1)	137.5 (75.5)	137.2 (74.6)
PO_{peak} (W)	29.4 (15.0)	26.8 (11.5)	28.2 (13.5)
VO_2 peak (l·min ⁻¹)	1.13 (0.49)	1.04 (0.42)	0.97 (0.36)
Untrained group ($n = 5$)			
F_{iso} (N)	92.1 (65.3)	116.3 (80.4)*	107.3 (69.5)*
PO_{peak} (W)	15.5 (9.2)	17.3 (10.3)	17.2 (9.4)
VO_2 peak (l·min ⁻¹)	0.59 (0.27)	0.65 (0.22)	0.62 (0.23)
Control group ($n = 7$)			
F_{iso} (N)	113.7 (72.3)	—	117.6 (74.6)
PO_{peak} (W)	15.0 (8.8)	—	17.2 (8.4)
VO_2 peak (l·min ⁻¹)	0.70 (0.26)	—	0.66 (0.19)

* Significant difference compared with t1, $p < 0.05$.

Table III. Results for physical strain during standardized ADL for each group in %HRR. Mean and standard deviations (in parentheses) are given. No significant differences were found between t1, t2 and t3

	t1	t2	t3
Trained group (n = 9)			
Ascending a ramp	42.3 (10.9)	40.7 (13.0)	42.1 (18.0)
Passing a door	31.7 (8.2)	32.6 (11.1)	32.9 (12.9)
Washing hands	35.0 (7.2)	35.7 (13.3)	39.1 (18.3)
Wheelchair propulsion (n = 8)	54.5 (17.4)	54.9 (25.0)	57.0 (24.7)
Untrained group (n = 5)			
Ascending a ramp (n = 4)	57.9 (6.4)	54.4 (13.6)	49.0 (6.3)
Passing a door	54.5 (8.0)	59.3 (17.7)	48.4 (11.1)
Washing hands	58.1 (8.8)	54.7 (10.7)	50.2 (7.6)
Wheelchair propulsion	67.5 (6.1)	72.6 (13.4)	71.4 (14.4)
Control group (n = 7)			
Ascending a ramp (n = 6)	51.0 (28.7)	–	54.3 (16.7)
Passing a door (n = 5)	46.4 (20.3)	–	49.9 (10.2)
Washing hands	46.5 (20.7)	–	46.1 (14.7)
Wheelchair propulsion	68.4 (19.2)	–	72.9 (16.6)

widely between subjects. Observed training time above 60 %HRR (21 and 42 minutes, for groups A and B, respectively) should have been sufficient to elicit a training effect, according to training guidelines for able-bodied persons (1) and results of previous training studies in persons with tetraplegia (2, 4, 10, 14). However, the large variation between subjects for training

time above 60 %HRR, as found in both groups, indicates that individual training intensity was probably not appropriate for all subjects. Establishing the optimal intensity and frequency of training for persons with tetraplegia should be the goal of future research.

CONCLUSIONS

Results of the present study showed no measurable improvements in VO_{2peak}, PO_{peak} and PS during standardized ADL after a non-controlled 6-month quad rugby training program, whereas a significant increase in maximal isometric strength was found. These results suggest that a higher training frequency and/or training intensity may be required in order to gain significant training effects for PO_{peak}, VO_{2peak}, and PS in daily life, in persons with tetraplegia.

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Table IV. Training and playing time at an intensity above 60 %HRR during quad rugby training and matches, expressed as absolute time (TI60 [min]), and expressed as a percentage of total training or playing time (TI60 [%]). Mean and standard deviations (in parentheses) are given

	Trained group	Untrained group
Competition match	n = 7	n = 4
TI60 (min)	27.5 (22.3)	46.5 (19.3)
TI60 (%)	24.9 (20.2)	51.2 (18.7)
Training	n = 9	n = 5
TI60 (min)	21.3 (11.8)	42.2* (14.7)
TI60 (%)	28.6 (16.6)	56.4* (20.4)

* $p < 0.05$.

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