Spinal Cord (2002) 40, 513–518

www.nature.com/sc

Original Article

Perceived exertion and rehabilitation with wheelchair ergometer: comparison between patients with spinal cord injury and healthy subjects

CC Grange*[,1], MP Bougenot[1], A Groslambert[1], N Tordi[1] and JD Rouillon[1]

[1]*Laboratoire des sciences du sport et UFRSTAPS place St Jacques bât. Bichat 25030 Besancon, France*

Objectives: The purpose of this study was to compare the effects of a rehabilitation program on the perceived exertion (PE) and the cardioventilatory responses during exercise in healthy people and paraplegics.
Methods: A group of seven healthy persons (age 26.6 SD 6.2 years) and one of seven paraplegics (age 42 SD 15.9 years) participated in a rehabilitation program composed of Square Wave Exercise Tests (SWEET) during six weeks. The maximal oxygen uptake, the power output (PO), heart rate (HR) and measures of PE using the Borg CR 10 scale were investigated during a maximal graded test performed before and after the rehabilitation program. During the first SWEET session (SWEET 1) measures of PE and HR (base and peak) were also investigated and compared to the last session (SWEET 2) of the same absolute workload after the 6 weeks.
Results: Statistical analysis revealed no significant difference in both groups for PE between the two maximal graded tests. However, a significant decrease in the PE values ($P<0.01$) was observed in both groups during the SWEET 2. There was no significant difference in maximal HR between the two graded tests, but a significant decrease in HR ($P<0.0001$ for base HR and $P<0.001$ for peak HR) was observed in SWEET 2 compared to 1. The maximal tolerated power (MTP) and the peak oxygen uptake increased significantly in both healthy and paraplegic groups ($P<0.0001$ and $P<0.05$ respectively) after the 6 weeks of rehabilitation exercise.
Conclusion: The results of the present study suggest that PE could be used to control the exercise intensity during a rehabilitation training program for paraplegics, similar to healthy subjects. The increase in the peak oxygen uptake and MTP demonstrates the positive effects of the rehabilitation program on the physical fitness of the subjects.
Spinal Cord (2002) **40,** 513–518. doi:10.1038/sj.sc.3101353

Keywords: rehabilitation; paraplegics; perceived exertion; wheelchair ergometer

Introduction

A Spinal Cord Injury (SCI) causes physiological and functional disorders whose severity is more or less dependant on the level of injury. These disorders have an impact on the everyday life of paraplegics and often lead to a physiological deconditionning. Metabolic changes are also associated with the reduced activity following SCI. The limited activity often negatively affects the health of these people and leads to a debilitative cycle. Muscle atrophy could be observed, due to a decrease in the oxidative and glycolytic enzyme activity in arm muscles.[1] A risk of atherosclerosis,[2] a reduction of aerobic capacity[3] and other cardiovascular consequences[4] are linked with the lower basal metabolic rate of these patients. Furthermore, high density-lipoprotein (HDL) cholesterol levels are reduced in SCI patients.[1] In fact, the limited life-style may lead to a physiological deconditioning, increasing the risk of coronary disorders, obesity and diabetes.[5]

In this regard, it appears that regular physical activity may be a decisive factor for the well-being of paraplegics. It has been observed that a rehabilitation program improves the cardioventilatory functioning.[2,3,6–8]

One of the major problems encountered during a rehabilitation program is the ability to measure the level of fatigue after a given effort, without the use of special physiological equipment. Since only a single intense load of training is required to provoke beneficial adaptations for the individual,[5] it is

*Correspondence: CC Grange, Laboratoire des sciences du sport et UFRSTAPS place St Jacques bât. Bichat 25030 Besancon, France

important to have a measure of the strain a given exercise imposes on the individual to be sure the stimulus is sufficient to induce an adaptative response. Authors have tested perceived exertion (PE) and different rating scales in healthy people[9–12] and people affected by different pathologies during a training or rehabilitation program.[12–14] These rating scales permit subjects to control accurately the exercise intensity without using technical instrumentation (ie heart rate monitoring), that could be interesting for patients affected by SCI who do not have use of medical instrumentation. Previous studies have demonstrated that PE was linked with peripheral factors such as muscle pain, and cardioventilatory factors such as heart rate or oxygen uptake.[15] However, the exact influence of these factors is still unknown in paraplegics. An investigation of deconditioned subjects such as paraplegics may offer decisive data on the processes linked with PE.

Therefore, the purpose of this study was to compare the effects of a rehabilitation program on the PE and the cardioventilatory responses during exercise in healthy people and paraplegics.

Materials and methods

Subjects

A group of seven healthy males (age 26.6 SD 6.2 years) and a group of seven old paraplegic males (age 35.2 SD 15.9 years, time since occurence of SCI 12.3 SD 10 years) volunteered to participate to this experiment after having been informed about the procedure, and signed an informed consent. Results from a standard health questionnaire, clinical and electrocardiogram examinations were normal for all subjects. According to the American Spinal Injury Association (ASIA) classification rules paraplegics were classified as ASIA A. The subject characteristics are presented in Table 1. All subjects were physically active without specific upper limb training. Our local ethical committee has approved this study. The experiments comply with the current laws of France.

Methods

All subjects performed a maximal graded exercise test (GXT)[16–19] on an ergometer (VP100H–HEF tecmachine, Andrezieux Boutheon, France) using the personal wheelchair for the paraplegics and a classic wheelchair for the healthy subjects (seat dimensions 15 inches by 18 inches, seat height 30 inches) with the position always held constant.[20] However, by means of a foam cushion, each subject could adjust their arm position. The ergometer had a single motorized roller with enslaved braking, and an electromagnetic system.[21] This system was controlled by specific software which allows the subject to work at a pre-determined speed. During the exercise, subjects could see all of the information concerning PO and speed.

After 6 min of quiet sitting in the wheelchair ergometer, the subject performed a progressive exercise test at a constant speed and 30 rpm[16,17] with no load. The load was increased from 0 W by 10 W every 2 min until exhaustion. The protocol of this test has been previously established by Predine *et al*[16] after several trials at various loads (5, 10, 20, 30 watts), duration (1, 2, 3 min) and velocities (30, 60, 90 rpm). The same authors showed that this test is reproducible, allows a warm-up, and was in every case long enough to ensure the measure of the maximal tolerated power (MTP), peak oxygen uptake and maximum HR.

The highest load which could be maintained with a constant speed of the ergometer for 1 min was taken as the MTP. The end point of the test was determined when the subject could not maintain the expected cadence or power output.

Expired gases were sampled and analyzed every 30 s with an Oxycon Champion analyzer (Mijnhardt®), calibrated before each test. The respiratory parameters monitored included oxygen uptake (VO_2, $ml.min^{-1}.kg^{-1}$. Heart rate (HR, bpm) was monitored continuously during the test by telemetry (PE 4000 sport tester). The perceived exertion and perceived pain were measured by the BORG CR 10[12] immediately at the end of the GXT.

Training period The training program consisted of three sessions per week for 6 weeks. Each session consisted of a 45 min SWEET for both groups proposed by Gimenez *et al*.[19,20] This particular type of exercise, used work rates established from the ventilatory threshold (VT) and the MTP of the progressive test, consisting of successive work bouts of 5-min duration. During each work bout, a 4 min period of moderate work, termed 'base' level, was

Table 1 Characteristics of subjects of the two gruops

Subjects	*Age* (year)	*Height* (cm)	*Weight* (kg)	*BMI* (%)	*T SCI* (year)
Healthy	26.6 SD 6.2	176.4 SD 5.3	76 SD 7.9	24.1 SD 2.3	–
(*n*=7)	[21–38]	[170–181]	[62–83]	[21.3–27.4]	
Paraplegics	35.2 SD 15.9	175.7 SD 5.5	72.8 SD 12	23.4 SD 3.2	12.3 SD 10
(*n*=7)	[21–50]	[170–182]	[57–86]	[19.7–28.7]	[1–30]

n=number of subjects; SD=standard deviation; BMI=body mass index; T SCI=time of spinal cord injury; Brackets [ ] represent extreme values followed by a 1 min period of heavy work, termed 'peak' level. Initially the base is set at a work rate corresponding to the VT and the peak at the MTP. The maximum intensity of endurance (MIE_{45}) was defined by both maximal HR at the end of the last peak and the inability for the subject to finish a training session. The peak and the base loads were alternately readjusted (+10 W) each time the heart rate at the end of the test was decreased by 10 bpm compared to the last increase. So, each training period was designed to be performed at the MIE_{45}.

The maximal graded exercise tests and the SWEET were performed before (GXT 1 and SWEET 1) and after a 6-week training period (GXT 2 and SWEET 2). All tests, including the training session were performed under medical supervision. Attendance at the training sessions was excellent, every subject followed the experimental protocol and has fully realized the program training session. To assess the effects of training, the last training session (SWEET 2) was performed at the same work load as the first (SWEET 1). At the end of each SWEET, subjects pointed on the CR 10 scale to a number that corresponded with his or her perception of effort and pain.

Statistical analysis
Data were analyzed with a two-way analysis of variance (groups × measurements) and a Scheffé's *post hoc* test for individual differences. Values are presented as means (M) and standard deviation (SD).

Results

Maximal graded tests (Table 2)
Analysis of variance of PE revealed no significant main effects in either group between GXT 1 and GXT 2. A significant main effect for groups for Perceived pain (PP) was observed ($F_{1,\ 11}=5.037$, $P<0.05$). Scheffe's *post hoc* test revealed a PP lower for paraplegics for the GXT 1 (M = 3.25 SD 4.2) compared to the healthy subjects (M = 5 SD 2) and for the GXT 2 (M = 2.58 SD 2.2 and M = 6 SD 1.6 respectively). However, no significant effect for measurement was observed.

Analysis of variance of maximal HR revealed no significant main effect in either group between GXT 1 and GXT 2.

A significant main effect for measurements of MTP ($F_{1,\ 11}=66.296$, $P<0.0001$) was found. Scheffé's *post hoc* test revealed a significant increase for both groups between GXT 1 (M = 73.7 W SD 12.6 for paraplegics and M = 61.6 W SD 16 for healthy) and GXT 2 (M = 88.1 W SD 18.2 and M = 89.3 W SD 15 respectively). Furthermore, a significant main effect for group and measurement ($F_{1,\ 11}=6.589$, $P<0.05$) was found. MTP of the healthy group was significantly higher than paraplegics before and after training and the increase of healthy group was significantly higher than the paraplegic group. Peak oxygen uptake significantly increased for both groups ($F_{1,\ 11}=7.951$, $P<0.05$) from GXT 1 (M = 27.73 $ml.min^{-1}.kg^{-1}$ SD 6.1 for paraplegics and M = 34.66 $ml.min^{-1}.kg^{-1} \pm 4.9$ for healthy) to GXT 2 (M = 32 $ml.min^{-1}.kg^{-1}$ SD 6 for paraplegics and 37.54 $ml.min^{-1}.kg^{-1}$ SD 4.3 for healthy). However, a significant group effect ($F_{1,11}=5.171$, $P<0.05$) was found. The maximal oxygen uptake was significantly higher in the healthy group for both tests.

SWEET Tests: (Table 3)
A significant main effect for measurement of PE was observed ($F_{1,\ 11}=16.348$, $P<0.01$). PE was significantly lower for SWEET 2 for both groups (M = 2 SD 1.2 for paraplegics and M = 2.5 SD 1.1 for healthy) compared to SWEET 1 (M = 4.86 SD 2.5 and M = 5.14 SD 1.3 respectively). However, no main effect of group was observed. A significant main effect for measurement of PP was observed ($F_{1,\ 11}=5.865$, $P<0.05$). PP was significantly lower for SWEET 2 for both groups (M = 1.04 SD 1.9 for paraplegics and M = 0.5 SD 0.6 for healthy) than SWEET 1 (M = 2.07 SD 2.9 and M = 3.69 SD 2.1 respectively). Nevertheless, no main effect of group was observed.

Table 2 Mean values and standard deviation (SD) of perceived exertion, heart rate, maximal tolerated power and maximal oxygen uptake measured during the maximal graded exercises before (GXT 1) and after (GXT 2) a rehabilitation training program performed by paraplegics and healthy subjects

	Perceived exertion		*Maximal tolerated power* (Watt)		*Heart rate* (bpm)		*VO_2 peak* ($ml\ min^{-1}\ kg^{-1}$)	
	GXT 1	*GXT 2*	*GXT 1*	*GXT 2*	*GXT 1*	*GXT 2*	*GXT 1*	*GXT 2*
Paraplegics	6.29	6.07	73.71	88.14	176.71	174.29	27.73	32
	SD 3.4	SD 3.5	SD 12.6	SD 18.2	SD 19.4	SD 14.9	SD 6.1[a]	SD 7
	[3–12]	[2.5–12]	[50–90][c]	[54–108]	[134–191]	[145–190]	[20.5–32.5][b]	[21.5–34.1]
Healthy	5.86	7.14	61.57	89.29	182.29	187.14	34.66	37.54
	SD 1.5	SD 1.1	SD 16	SD 15	SD 10.5	SD 6.6	SD 4.9[a]	SD 4.3
	[4–8]	[6–9]	[40–90]	[70–118]	[170–201]	[180–196]	[27.6–41.5]	[29.3–45.7]

Brackets [ ] represent extreme values. [a]$P<0.05$ between GXT1 and GXT2; [b]$P<0.05$ and [c]$P<0.0001$ between both groups

Table 3 Mean values and standard deviation (SD) of base heart rate, peak heart rate, perceived exertion and perceived pain measured at the beginning (SWEET 1) and at the end (SWEET 2) of a rehabilitation training program performed by paraplegics and health subjects

	Base HR (bpm)		*Peak HR* (bpm)		*Perceived exertion*		*Perceived pain*	
	SW1	*SW2*	*SW1*	*SW2*	*SW1*	*SW2*	*SW1*	*SW2*
Paraplegics	149.18	135.06	157.96	146.71	4.86	2	2.07	1.04
	SD 20.6[d]	SD 20.2	SD 24.6[c]	SD 25.9	SD 2.5[b]	SD 1.2	SD 2.9[a]	SD 1.9
	[117.1–173]	[103.6–161]	[116.1–188]	[103.7–179]	[3–10]	[0–3]	[0–8]	[0–5]
Healthy	145.71	117.57	164.71	129.57	5.14	2.5	3.69	0.5
	SD 21.8[d]	SD 19.4	SD 18.8[c]	SD 20.7	SD 1.3[b]	SD 1.1	SD 2.1[a]	SD 0.6
	[114–181]	[89–147]	[132–190]	[00–162]	[3–7]	[1–4]	[0.3–6]	[0–1.5]

Brackets [ ] represent extreme values. [a]$P<0.05$; [b]$P<0.01$; [c]$P<0.001$; [d]$P<0.0001$ between SWEET 1 and SWEET 2

A significant main effect of measurement was observed in the 'base' HR ($F_{1,11}=36.059$, $P<0.0001$). *Post hoc* test revealed a significant decrease between SWEET 1 for both groups (M = 149.18 bpm SD 20.6 for paraplegics and M = 145.71 bpm SD 21.8 for healthy) and SWEET 2 (M = 135.06 bpm SD 20.2 and M = 117.57 bpm SD 19.4 respectively). A significant main effect of measurement was found in 'peak' HR ($F_{1,\ 11}=26.995$, $P<0.001$). The peak HR was significantly higher in SWEET 1 for both groups (M = 157.96 bpm SD 24.6 for paraplegics and M = 164.71 bpm SD 18.8 for healthy) compared to SWEET 2 (M = 146.71 bpm SD 25.9 and M = 129.57 bpm SD 20.7 respectively). However, a significant interaction ($F_{1,11}=7.165$, $P<0.05$) between groups and measurements was observed. The decrease of peak HR was higher for healthy than paraplegics.

Discussion

Firstly, the results must be interpreted with some precautions because of the relatively small size of both groups. Further investigations carried out on a large experimental population must confirm our results. Previous studies have reported that HR and perceived exertion were variables significantly correlated.[9,10,11,15] The fact that no difference of PE was found between the two groups during the two GXT suggests that paraplegics of the present study felt the same perceived exertion as healthy people. Furthermore the results of this study show no significant difference between the two groups in peak HR between the two GXT and between the two SWEET tests. It appears as though both populations have the same heart rate responses during the rehabilitation program. It may be expected that the groups have different responses to the training, but these results may be possible because the paraplegic patients in this study were heterogeneous and the standard deviation of HR was greater, involving no significant difference.[4] However, previous studies have reported in healthy subjects that perceived exertion can be used to control exercise intensity during continuous[9,11,13] or intermittent training.[22] Therefore, it may be suggested that exercise intensity could also be controlled by perceived exertion in paraplegic subjects without depending on any biofeedback monitoring system (ie heart rate monitoring).[9,12]

The fact that no significant difference was found in HR and PE between GXT 1 and GXT 2 indicated that maximal graded exercises were performed at the same relative intensity. The significant decrease of PE and HR values observed during SWEET 2 compared to SWEET 1 at the same power output demonstrates the positive effects of the rehabilitation training program on the physiological responses of subjects. Other authors have found similar findings.[4,7]

A difference in the perception of pain was observed between GXT 1 and GXT 2 between the two groups. The paraplegics seem to feel less pain compared to healthy subjects during exercise. This result may be explained by different past ways of life of each group.[8] Indeed, paraplegics have a different approach of pain because of their spinal cord injury.[14] Also, the difference of pain feeling could be explained by the fact that old injury paraplegics tested in the present study are trained for a long time to use their arms to move their wheelchair.

However, a difference in perception of pain in both groups was observed between the SWEET tests. This result further supports the positive effects of the rehabilitation program for both groups. It is likely that the rehabilitation program develops specific peripheral muscular adaptations against pain. The absolute work loads were the same between both tests, but the relative work loads were lower.

The results show significant changes in the maximal tolerated power and oxygen uptake in both groups between the two maximal graded tests showing the positive adaptations of the rehabilitation program. However, the training effects are more significant in the healthy people than in the paraplegics. The paraplegics and the healthy people have different adaptations of their thermoregulatory systems and of their arterial pressure during exertion.[14]

The thermal regulation disorders of paraplegics cause hypothermia at rest and hyperthermia at exercise that may create limitations in the metabolism and also diminishing sweat responses. The regulation of cellular and extracellular hydration is disturbed, altering the exercise capacity. These disorders may influence the arterial tension, which may result in a decreased exercise intensity supported by paraplegics. These diminished responses or lack of adaptations compared to healthy subjects arises directly from primary complications associated with the spinal injury. Moreover, the healthy subjects did not have experience of handrim propulsion in wheelchair and there improvement could be better than the paraplegics.[23] Therefore, all these parameters suggest that the training effects are less significant for paraplegics than healthy subjects. Furthermore, the ventilatory responses of paraplegics may also be affected by decreased efficiency of the inspiratory muscles and their improvement may not be as great compared to the healthy subjects.[3] However, it appears that these ventilatory disorders do not significantly affect perceived exertion of paraplegic patients, as it does with cardiac patients with chest pain.[15] Finally, as oxygen uptake decrease with increasing age,[24] it is possible that the significant changes in the maximal oxygen uptake observed between both groups could also be influenced by the age difference of the subjects. The time elapsed since occurence of SCI may also influence the rehabilitation capacities of patients. However, the fact that only old spinal cord-injured patients were tested in the present study does not allow to determine influence of this variable.

Conclusion

Our results suggest that the spinal cord injury does not influence perceived exertion of old SCI patients compared to healthy subjects. Their training capacities seem to be real, although the paraplegic patients were older than the healthy subjects. Thus, these findings support the use of perceived exertion as a useful measure of exercise intensity for the rehabilitation purposes of paraplegic patients. Further investigations are needed to determine the use of perceived exertion as a means of self-regulation of a rehabilitation program.

Acknowledgement

We especially thank Andrew Betik for his precious help.

References

1 Hoffman MD. Cardiorespiratory fitness and training in quadraplegics and paraplegics. *Sports Med* 1986; **3:** 312–330.
2 Cowell LL, Squires WG, Raven PB. Benefits of aerobic exercise for the paraplegic: a brief review. *Med Sci Sports Exerc* 1986; **18:** 501–508.
3 Yamasaki M *et al*. Relationship between physical characteristics and physiological responses during maximal arm cranking in paraplegics. *Spinal Cord* 1998; **36:** 579–583.
4 Yim SY *et al*. Effect of wheelchair ergometer training on spinal cord-injured paraplegics. *Yonsei Medical Journal* 1993; **34:** 278–286.
5 Hooker SP, Wells CL. Effects of low and moderate intensity training in spinal cord injured persons. *Med Sci Sports Exerc* 1989; **21:** 18–22.
6 Hopman MTE, Verheijen PHE, Binkhorst RA. Volume changes in the legs of paraplegic subjects during arm exercise. *J Appl Physiol* 1993; **75:** 2079–2083.
7 Gass GC *et al*. The effects of physical training on high level spinal lesions patients. *Scand J Rehab Med* 1980; **12:** 61–65.
8 Maury M. La paraplégie. in: Flammarion médecine-science. Paris, 1981.
9 Dishman RK, Patton RW, Smith J, Jackson A. Using perceived exertion to prescribe and monitor exercise training heart rate. *Int J Sport Med* 1987; **8:** 208–213.
10 Borg G, Noble BJ. Perceived exertion. *Exerc Sport Sciences review* 1974; **5:** 131–153.
11 Borg G. Psychophysical scaling with application in physical work and the perception of exertion. *Scand J Work Environ Health* 1990; **16:** 55–58.
12 Borg G. (ed.). Perceived exertion and pain scales. In: *Human kinetics*. Illinois: Champaign, 1998; pp. 63–80.
13 Capodaglio P, Grilli C, Bazzini G. Tolerable exercise intensity in the early rehabilitation of paraplegic patients. A preliminary study. *Spinal Cord* 1996; **34:** 684–690.
14 Thomas TR, Ziogas G, Smith T, Zhang Q, Londeree BR. Physiological and perceived exertion responses to six modes of submaximal exercise. *Research Quater Exerc Sport* 1995; **66:** 239–246.
15 Noble BJ, Robertson RJ. (eds.). Perceived exertion. In: *Human kinetics*. Illinois: Champaign, 1996; pp. 105–287.
16 Predine E. Validation d'un fauteuil roulant ergomètre, des tests ergospirométriques et dynamométrique et de l'enregistrement électromyographique de la fatigue musculaire. Réponses ventilatoires, cardiocirculatoires, métaboliques et musculaires chez des personnes valides et handicapées au cours de l'exercice dynamique progressif. Thèse d'Université Nancy I, November 1993.
17 Predine E, Gimenez M. Mise au point et validation d'un prototype de fauteuil roulant ergomètre permettant la mesure d'efforts réalisés avec les membres supérieurs. *Medecine du sport* 1996; **70:** 17–24.
18 Gimenez M, Cereceda V, Teculescu D, Aug F, Laxenaire C. Square-Wave Endurance Exercise Test (SWEET) for training and assessment in trained and untrained subjects. Effect on VO_2 max and maximal ventilation. *Eur J Appl Physiol* 1982; **49:** 379–387.
19 Gimenez M *et al*. Implications of lower- and upper-limb training procedures in patients with chronic airway obstruction. *Chest* 1992; **101:** 279–288.
20 Gimenez M, Predine E, Marchand M, Kittstein G. Validation d'un fauteuil-roulant ergomètre pour la mesure de la réponse cardiorespiratoire et le rendement mécanique. *Archives Internationales de Physiologie, Biochimie et Physique* 1991; **99:** 102.
21 Devillard X *et al*. Développement d'un ergomètre pour fauteuil roulant: outil de mesure des capacités du patient à la propulsion d'un fauteuil roulant et choix à la prescription. [A wheelchair ergometer for physiological and biomechanical measurements.] *Fauteuil roulant. [The wheel chair]*. Paris: Masson, 1997; pp 134–142.

22 Fardy PS, Yanowitz FG, Wilson PK. *Cardiac rehabilitation, adult fitness and exercise testing*. 2nd edn. Philadelphia: Lea and Febiger, 1988.
23 Veeger HEJ, Van Der Woude LHV, Rozendal RH. Effect of handrim velocity on mechanical efficiency in wheelchair propulsion. *Med Sci Sports Exerc* 1992; **24:** 100–107.
24 Coudert J, Van Praagh E. Endurance exercise training in the elderly: effects on cardiovascular function. *Clin Nutrition Metab Care* 2000; **3:** 479–483.