Metabolic rate and cardiorespiratory response during hybrid cycling versus handcycling at equal subjective exercise intensity levels in people with spinal cord injury

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Objective: To compare the metabolic rate and cardiorespiratory response during hybrid cycling versus handcycling at equal subjective exercise intensity levels in people with spinal cord injury (SCI).

Design: Cross-sectional study.

Setting: Amsterdam Rehabilitation Research Centre | Reade, Amsterdam, The Netherlands.

Methods: On separate days, nine individuals with a motor complete paraplegia or tetraplegia (eight men, age 40 ± 13 years, time since injury 12 ± 10 years) performed 5-minute bouts of hybrid cycling (day 1) and handcycling (day 2) at moderate (level 3 on a 10-point rating of perceived exertion (RPE) scale) and vigorous (RPE level 6) subjective exercise intensity, while respiratory gas exchange was measured by open-circuit spirometry and heart rate was monitored using radiotelemetry.

Outcome measures: Metabolic rate (calculated with the Weir equation) and cardiorespiratory response (heart rate, oxygen pulse, and ventilation).

Results: Overall, the metabolic rate during hybrid cycling was 3.4 kJ (16%) higher ($P = 0.006$) than during handcycling. Furthermore, compared with handcycling, the overall heart rate and ventilation during hybrid cycling was 11 bpm (11%) and 5.3 l/minute (18%) higher ($P = 0.004$ and 0.024), respectively, while the oxygen pulse was the same ($P = 0.26$).

Conclusion: Hybrid cycling induces a higher metabolic rate and cardiorespiratory response at equal RPE levels than handcycling, suggesting that hybrid cycling is more suitable for fighting obesity and increasing cardiorespiratory fitness in individuals with SCI.

Keywords: Exercise, Obesity, Physical fitness, Spinal cord injuries

Introduction

People with spinal cord injury (SCI) have a reduced total daily energy expenditure, which can partly be explained by reduced physical activity levels as a result of their paralysis and subsequent wheelchair dependency.¹ The serious inactive lifestyle in people with SCI is associated with low cardiorespiratory fitness levels, obesity, and

obesity-related disorders (e.g. diabetes and cardiovascular disease).²⁻⁴ Furthermore, it is known that the work intensity of activities of daily life is not sufficient to improve or maintain the cardiorespiratory fitness and fight obesity in individuals with SCI.^{5,6} Therefore, it is important that people with SCI perform exercise training at sufficiently high metabolic rates.

However, due to the lower-limb paralysis, exercise training in people with SCI often involves upper-body activities (e.g. handcycling),^{7,8} which may limit successful health outcome due to the relatively small active

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muscle mass, inactivity of the skeletal muscle pump of the legs, and deficient cardiovascular reflex response.⁹ To alleviate these problems, the paralyzed lower-limb musculature can be added to the upper-body exercise by functional electrical stimulation (FES). Compared with upper-body exercise alone, this hybrid mode of exercise training (e.g. hybrid cycling) has the potential to induce higher levels of metabolic rate.^{9–11}

The metabolic rate an individual is able to exercise at for a certain period is largely dependent on the subjectively experienced exercise intensity, which can easily be assessed with a rating of perceived exertion (RPE) scale.¹² In people with SCI, this method seemed to be an appropriate measure for exercise intensity during moderate-to-vigorous steady-state exercise.^{13,14} Due to the limited active muscle mass, upper-body exercise alone may provoke high RPE levels at relatively low metabolic rates. Hybrid exercise might be a way to increase the metabolic rate as well as the cardiorespiratory response while exercising at equal RPE levels; however, this has not been investigated yet.

Therefore, the aim of this study was to compare the metabolic rate and cardiorespiratory response during hybrid cycling versus handcycling at equal RPE levels in a group of individuals with SCI. It was hypothesized that, due to the larger muscle mass available, hybrid cycling would lead to a higher metabolic rate and cardiorespiratory response and would therefore be more effective in fighting obesity and increasing cardiorespiratory fitness.

Methods

Participants

Nine individuals with a motor complete paraplegia or tetraplegia (Table 1) were recruited from the database of the local rehabilitation center, and participated in this study, which was approved by the Medical Ethics Committee of the VU University Medical Centre,

Amsterdam. All participants provided written informed consent indicating voluntary participation in this study. Individuals with a spastic paralysis and absent or limited sense in the lower body were eligible to be included if they responded well (visible muscle contractions and no discomfort in the lower extremities) to FES for at least 5 consecutive minutes. Individuals were excluded if they had contra-indications for physical testing, such as pressure sores, serious cardiovascular problems, or severe musculoskeletal complaints. Participants refrained from strenuous exercise for at least 48 hours before the tests. Furthermore, participants were requested to consume their last meal at least 2 hours prior to testing, and to avoid caffeine and alcohol consumption in the 24 hours before testing.

Study design

This cross-sectional study was performed in the local rehabilitation center. During the first measurement occasion, all participants performed an exercise protocol on a hybrid cycle; during the second measurement occasion, an exercise protocol was performed on a handcycle (see the section on “Protocol” and Fig. 3 for more details regarding the different exercise protocols). To provide sufficient recovery time, 48–72 hours of relative rest was scheduled in between measurement occasions.

Exercise modalities

Hybrid cycle

The hybrid cycle (BerkelBike Pro, BerkelBike B.V., St Michielsgestel, the Netherlands; Fig. 1) combines synchronous handcycling with asynchronous FES-induced leg cycling. A 6-channel stimulator (Impuls, BerkelBike B.V.; Fig. 1A) provides the electrical stimulation via 12 self-adhesive 50 × 90 mm² surface electrodes (Stimex, Pierenkemper GmbH, Ehringshausen, Germany) placed bilaterally over the quadriceps, hamstrings, and gluteus muscles. The stimulator receives

Table 1 Demographics of the participants

Participant	Sex	Age (years)	TSI (years)	Lesion level	AIS	Height (cm)	Weight (kg)	BMI (kg/m ²)
1	m	53	11	C7	C	180	65	20
2	m	40	19	T6	A	187	66	19
3	m	56	4	T7	A	176	85	27
4	m	25	4	T8	A	193	70	19
5	m	55	34	C3	C	175	91	30
6	m	30	12	T11	A	185	74	22
7	f	40	4	C7	C	186	68	20
8	m	31	6	C8	A	180	59	18
9	m	26	10	C6	A	189	78	22
Mean (SD)		40 (13)	12 (10)			183 (6)	73 (10)	22 (4)

m, male; f, female; TSI, time since injury; AIS, ASIA (American Spinal Injury Association) Impairment Scale; BMI, body mass index; SD, standard deviation.

Figure 1 The hybrid cycle with the stimulator (A) and crank angle encoder (B) mounted on an ergotrainer (C).

information from the crank angle encoder (Fig. 1B) about pedal position and velocity to control the cyclic stimulation pattern. The stimulator has five preset stimulation programs, each with the same pulse duration (400 μ s) and maximal current amplitude (150 mA), but with different stimulation frequencies (20–35 Hz) and FES firing angles. During cycling, the current amplitude of the electrical stimulation can be changed manually with steps of 15 mA. The hybrid cycle is equipped with eight gears, and if necessary, quad grips can be mounted.

The handcycle

The handcycle (Speedy-Bike, Reha-Technik GmbH, Delbrück, Germany; Fig. 2) is equipped with a wide synchronous bull-horn crank and with eight gears that can be changed manually. If necessary, the handcycle can also be equipped with quad grips.

The front wheel of both cycles was mounted on an ergotrainer (Tacx Flow, Technische Industrie, Tacx B.V., Wassenaar, The Netherlands; Figs. 1C and 2A) that was adapted to the wheel size of the cycles.

Protocol

Both measurement sessions consisted of a 2-minute warm-up and cool-down session of voluntary handcycling in the specific test cycle (in case of the hybrid cycle this meant that the legs were moved passively). After the warm-up, the first 5-minute exercise bout was performed at moderate subjective exercise intensity (RPE level 3 on the Borg category ratio 10 (CR10) scale),¹² and after a 5-minute rest interval, the second 5-minute exercise bout was performed at vigorous subjective exercise intensity (RPE level 6; Fig. 3).

Before starting with the hybrid cycle test, first the participant's response to the five different stimulation programs was tested to examine the most suitable program for exercise testing. Since each program has different stimulation parameters (as described in the section on "Exercise modalities"), individuals may respond differently to these programs; for example, it might be that a specific stimulation program induces discomfort in the lower limbs or a less smooth cycling motion. Based on subjective observations of the researcher and the perception of the participant, the

Figure 2 The handcycle mounted on an ergotrainer (A).

Figure 3 Exercise protocol. Warm-up and cool-down sessions consisted of voluntary handcycling in the specific test cycle.

program that produced the smoothest cycling motion without inducing discomfort was selected.

Before testing, the researcher extensively explained the Borg CR10 scale to the participants and indicated that the imposed RPE levels should reflect their overall perceived exertion (integrated sensation of central and peripheral stress). The participants were asked to maintain the imposed RPE levels as good as possible during all 5-minute exercise bouts. In order to do so, at any time during cycling participants were able to adjust the cycle velocity or ask the researcher to adjust the gear of the cycle or the resistance of the ergotrainer; in addition, during hybrid cycling the current amplitude of the stimulation could be adjusted manually by the researcher to control the degree of muscle activation. The researcher tried to induce strong lower-body muscle contractions; however, the current amplitude was decreased if the legs were moving too fiercely due to the stimulation or if the participants indicated that the stimulation was too intense.

During testing, the respiratory gas exchange was measured using open-circuit spirometry (K4b², COSMED, Rome, Italy), the heart rate was monitored using radiotelemetry (Polar, Polar Electro Inc., Woodbury, NY, USA), and the power output was measured using a power meter (PowerTap Pro+, CycleOps, Madison, WI, USA) that was mounted on the front wheel of both cycles.

Outcome measures

The main outcome measures of this study were the metabolic rate and cardiorespiratory response. The metabolic rate (kJ/minute) was calculated with the Weir method: $3.942 \times \text{VO}_2$ (l/minute) + VCO_2 (l/minute) $\times 4.182$,¹⁵ where VO_2 (l/minute) and VCO_2 (l/minute) were the average oxygen uptake and carbon dioxide emission during the last minute of the steady-state exercise bouts, respectively. Measures for the cardiorespiratory response were heart rate, oxygen pulse (a

surrogate for stroke volume and arteriovenous oxygen difference), and ventilation (V_E); the average heart rate (bpm) and V_E (l/minute) over the last minute of the bouts were used for analysis. Oxygen pulse (ml/beat) was calculated by dividing VO_2 (l/minute) by the heart rate (bpm). A secondary outcome measure was the power output (W) over the last minute of the exercise bouts.

Statistics

The assumption of normality was checked by visual inspection of the q - q plot and box plot of the data within the groups; in addition, a Shapiro-Wilk's test was performed on the data. Since there were no violations of these assumptions, the effect of exercise modality (hybrid cycling, handcycling) and subjective exercise intensity (RPE level 3, RPE level 6) on the outcome measures was examined with two-way repeated-measures analysis of variance. If there was a significant interaction (or tendency to an interaction), paired t -tests were used to examine this interaction and to calculate the 95% confidence interval (CI) for each difference between the means. Partial eta-squared (η_p^2) was calculated to determine the effect size.

Results

Metabolic rate

There was a significant main effect for both exercise modality ($F(1,8) = 13.55$, $P = 0.006$, $\eta_p^2 = 0.63$) and exercise intensity ($F(1,8) = 23.73$, $P = 0.001$, $\eta_p^2 = 0.75$). Overall, compared with handcycling, the metabolic rate during hybrid cycling was 3.4 kJ/minute (95% CI = 1.3, 5.6) higher; and compared with RPE level 3, the metabolic rate at level 6 was 6.7 kJ/minute (95% CI = 3.5, 9.9) higher (Fig. 4). The interaction between exercise modality and exercise intensity was also significant ($F(1,8) = 5.98$, $P = 0.04$, $\eta_p^2 = 0.43$). Follow-up analyses on the significant interaction revealed that the difference in metabolic rate between hybrid cycling and handcycling was higher at RPE

Figure 4 Absolute metabolic rate (mean + standard error) for handcycling (dark gray) and hybrid cycling (light gray) at RPE levels 3 and 6 (* $P < 0.05$; ** $P < 0.01$).

level 6 (4.4 kJ/minute (95% CI = 1.8, 7.0)) than at level 3 (2.5 kJ/minute (95% CI = 0.4, 4.5)). Furthermore, the difference in metabolic rate between RPE levels 3 and 6 was higher for hybrid cycling (7.7 kJ/minute (95% CI = 3.9, 11.4)) than for handcycling (5.8 kJ/minute (95% CI = 3, 8.5)).

Cardiorespiratory response

Heart rate

A significant main effect was found for both exercise modality ($F(1,7) = 18.18$, $P = 0.004$, $\eta_p^2 = 0.72$) and exercise intensity ($F(1,7) = 19.28$, $P = 0.003$, $\eta_p^2 = 0.73$). Overall, compared with handcycling, mean heart rate during hybrid cycling was 11 bpm (95% CI = 5, 18) higher; and compared with RPE level 3, mean heart rate at level 6 was 21 bpm (95% CI = 10, 32) higher (Fig. 5A). A tendency to an interaction effect was found ($F(1,7) = 4.18$, $P = 0.08$, $\eta_p^2 = 0.37$). Follow-up analyses revealed that the difference in heart rate between hybrid cycling and handcycling was higher at RPE level 6 (17 bpm (95% CI = 7, 27)) than at level 3 (3 bpm (95% CI = -6, 12)). Furthermore, the difference in heart rate between RPE levels 3 and 6 was higher for hybrid cycling (27 bpm (95% CI = 12, 41)) than for handcycling (15 bpm (95% CI = 7, 23)).

Oxygen pulse

There was a significant main effect for exercise intensity ($F(1,7) = 15.96$, $P = 0.005$, $\eta_p^2 = 0.70$). Overall, the mean oxygen pulse at RPE level 6 was 1.25 ml/beat (95% CI = 0.51, 1.99) higher than at level 3 (Fig. 5B). No

Figure 5 Cardiorespiratory response (heart rate (top), oxygen pulse (middle) and V_E (bottom)) during handcycling (dark gray) and hybrid cycling (light gray) at RPE levels 3 and 6 (** $P < 0.01$). Values are mean + standard error.

significant main effect for exercise modality ($F(1,7) = 1.49$, $P = 0.26$, $\eta_p^2 = 0.18$) or interaction effect ($F(1,7) = 0.47$, $P = 0.51$, $\eta_p^2 = 0.06$) was found.

Ventilation

There was a significant main effect for both exercise modality ($F(1,8) = 7.77$, $P = 0.024$, $\eta_p^2 = 0.49$) and exercise intensity ($F(1,8) = 65.22$, $P < 0.001$, $\eta_p^2 = 0.89$). Overall, compared with handcycling, mean V_E during hybrid cycling was 5.3 l/minute (95% CI = 0.9, 9.6) higher; and compared with RPE level 3, mean V_E at level 6 was 12.9 l/minute (95% CI = 9.3, 16.7) higher (Fig. 5C). The interaction between exercise modality and exercise intensity was also significant ($F(1,8) = 11.315$, $P = 0.01$, $\eta_p^2 = 0.59$). Follow-up analyses on the significant interaction revealed that the difference in V_E between hybrid cycling and handcycling was higher at RPE level 6 (7.7 l/minute (95% CI = 2.6, 12.8)) than at level 3 (2.8 l/minute (95% CI = -1.4, 6.9)). Furthermore, the difference in V_E between RPE levels 3 and 6 was higher for hybrid cycling (15.5 l/minute (95% CI = 10.4, 20.5)) than for handcycling (10.5 l/minute (95% CI = 7.7, 13.3)).

Power output

There was a significant main effect for exercise intensity ($F(1,7) = 35.21$, $P = 0.001$, $\eta_p^2 = 0.83$). Overall, compared with RPE level 3, the power output at RPE level 6 was 13.86 W (95% CI = 8.34, 19.38) higher. No significant main effect for exercise modality ($F(1,7) = 1.12$, $P = 0.32$, $\eta_p^2 = 0.14$) or interaction effect ($F(1,7) = 1.60$, $P = 0.25$, $\eta_p^2 = 0.19$) was found.

Discussion

An important result of this study was that the metabolic rate during hybrid cycling was higher than during handcycling at equal RPE levels (Fig. 4). Several other studies also found higher metabolic rates during hybrid exercise versus arm exercise alone,^{9,16,17} and stated that this was caused by the larger active muscle mass during hybrid exercise. In these studies, power output was used to standardize the exercise intensity; however, since RPE was not measured, it remained unclear how the participants subjectively experienced the exercise intensity during the relatively short (i.e. 10 minutes) exercise bouts. It might be possible that the higher metabolic rates in the above-mentioned studies also coincided with higher RPE levels. If this was the case, it is likely that these metabolic rates could not be maintained during a longer exercise period (e.g. 30–60 minutes), resulting in a necessary decrease in metabolic rate to be able to finish the exercise period. Eventually, it might be possible that the average

metabolic rate over that certain exercise period will be nearly the same for both exercise modalities. The additional value of the current study is that it was demonstrated that the higher metabolic rate during hybrid cycling was achieved while “feeling the same” as during the handcycling bouts. A secondary finding was that the absolute difference in metabolic rate between both exercise modalities was higher at RPE level 6 compared with level 3 (Fig. 4). Hence, the above-described results show that people with SCI expend more energy during hybrid cycling than during handcycling, and that this benefit becomes higher at increased RPE levels. These findings suggest that hybrid exercise might be more suitable for fighting obesity than arm exercise alone (when energy intake is kept constant). However, more research is needed regarding the required duration, frequency, and intensity of exercise to fight obesity.

The higher metabolic rate during hybrid cycling coincided with a higher V_E and heart rate (Fig. 5). Since other studies^{9,16,18,19} found higher stroke volumes during hybrid exercise compared with arm exercise alone, indicating an increased cardiac volume loading as a result of the activation of the leg muscle pump, oxygen pulse was also expected to be higher during hybrid cycling; However, in this study, oxygen pulse did not differ between exercise modalities (Fig. 5). Nevertheless, the higher V_E and heart rate at a similar oxygen pulse indicate that hybrid cycling gives a higher training stimulus to the heart and lungs compared with handcycling, suggesting that hybrid cycling is more suitable for increasing cardiorespiratory fitness.

Despite the higher metabolic rate during hybrid cycling, no difference in external power output was observed, which can be explained by the fact that hybrid cycling is less efficient than handcycling.¹⁶

A possible limitation of this study was that the type of cycling was not randomized (each participant started with the hybrid cycle protocol). This might have caused systematic differences between measurement occasions (e.g. learning effect regarding Borg scale interpretation). However, it was not expected that randomization of the exercise modes would have changed the results and outweighed the positive effects of the much larger muscle mass that is used during hybrid cycling. Another limitation was that the exercise bouts, during which the outcome measures were determined, were relatively short (i.e. 5 minutes). During the 5-minute bouts, all participants responded very well to the FES, but we know that this response often decreases over time. In daily practice, people should exercise for a much longer period to obtain desirable training effects.²⁰ From the current study, it remained unclear whether the metabolic rate and cardiorespiratory response during hybrid cycling are still higher during a longer

exercise period, where relatively untrained lower-limb muscles become fatigued over time. Therefore, future research is needed to examine whether the beneficial effects of hybrid cycling on metabolic rate and cardiorespiratory response still hold during longer exercise periods (e.g. 30 minutes), keeping in mind that it might be necessary to first properly train the lower-limb musculature to ensure strong muscle contractions over the entire exercise period.

Altogether, the results of the current study suggest that people with SCI should implement hybrid exercise training in daily life. Hybrid/FES exercise is not only good to lose weight and to become and stay fit, many other studies also suggest benefits on vascular,^{21–23} muscle,^{24,25} and bone systems²⁶ in the lower extremities.

Conclusion

This study demonstrated that hybrid cycling induces a higher metabolic rate and cardiorespiratory response at equal RPE levels compared with handcycling, suggesting that hybrid cycling is more suitable for fighting obesity and increasing cardiorespiratory fitness in individuals with SCI.

Disclaimer statements

Contributors AB: concept/idea/research design, patient recruitment, data analysis, drafting the article. SdG: concept/idea/research design, data analysis, revising the article. MO: concept/idea/research design, patient recruitment, data collection, data analysis, drafting the article. JdJ: concept/idea/research design, patient recruitment, data collection, data analysis, drafting the article. TJ: Concept/idea/research design, data analysis, revising the article.

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Conflicts of interest None.

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