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Recumbent Cross-Training Is a Feasible and Safe Mode of Physical Activity for Significantly Motor-Impaired Adults With Cerebral Palsy

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Abstract

Objective—To examine the feasibility and potential benefits of using recumbent cross-training for nonambulatory adults with cerebral palsy (CP).

Design—Observational.

Setting—Clinical center for CP treatment and rehabilitation.

Participants—Significantly motor-impaired adults with CP (NZ = 11) with a mean age $\pm$ SD of 36.3 $\pm$ 13.2 years and Gross Motor Function Classification System (GMFCS) III and IV.

Interventions—Participants completed a 40-minute session of aerobic exercise using the NuStep Recumbent Cross Trainer, in which resistance was progressively increased at 5-minute intervals.

Main Outcome Measures—Every 5 minutes during the exercise session, heart rate, blood pressure, oxygen consumption ($\dot{V} O_2$), energy expenditure, and respiratory exchange ratios (RERs) were recorded along with rating of perceived exertion. Immediately after, and 24 hours postexercise, participants received a standard survey to assess levels of pain and discomfort.

Results—All participants were able to complete the 40-minute exercise protocol. Five of the 11 participants achieved a heart rate of at least 60% maximum throughout the duration, 10 participants had a significant elevation in $\dot{V} O_2$ from baseline, and all participants had elevated

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Suppliers

- Polar heart rate monitor; Polar Electro Inc, 1111 Marcus Ave, Ste M15, Lake Success, NY 11042-1034.
- Cosmed K4b² portable metabolic cart; Cosmed, Via dei Piani di Mt. Savello 37, Pavona di Albano-Rome, I-00041, Italy.
- NuStep Inc, 5111 Venture Dr, Ste 1, Ann Arbor, MI 48108. d. SAS Institute Inc, 100 SAS Campus Dr, Cary, NC 27513.

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RER values. Six participants reported pain during exercise, but only 2 reported pain after exercise was over.

Conclusions—The NuStep Recumbent Cross Trainer is a feasible exercise modality for significantly motor-impaired adults with CP, GMFCS III and IV. Moreover, this mode was sufficient to stimulate a significant cardiorespiratory response in all participants, and thus it and similar devices may serve as a viable option for aerobic exercise interventions in this population, to prevent obesity and related cardiometabolic consequences.

Keywords

Aerobic exercise; Cerebral palsy; Gait dysfunction; Pain; Rehabilitation

Cerebral palsy (CP) is a group of disorders that affect the development of movement and posture, resulting in significant activity limitations. Although CP is a chronic and permanent condition, most existing research is focused on the status and interventions for children with CP.¹ Moreover, and from a clinical context, there is no standard or systematic follow-up of individuals with CP after the age of 18 years, with little attention devoted to adults and the elderly.² Families of children with CP are often told that health, functional status, mobility, and musculoskeletal problems become relatively stable by early adulthood; however, as more people with motor disabilities live beyond middle and later adulthood, it has become increasingly evident that changes in health status and function may be of concern.³ Importantly, individuals with CP are subject to the same secondary health risks as typically developing adults, such as obesity-related chronic disease, muscle atrophy and weakness, and reduced functional mobility.⁴ Thus, in conjunction with the hallmark pain and chronic fatigue associated with CP,⁵ these interrelated circumstances represent a unique challenge for the medical community regarding treatment of adults with CP and appropriate interventions that preserve patient health, function, and quality of life.³

As adults with CP age, they experience an overall decline in physical functioning and become increasingly reliant on assistance to perform many activities of daily living.^{6,7} To make matters worse, ample evidence exists to confirm that individuals with CP have lower fitness,^{8,9} less muscle mass,¹⁰ diminished bone density,^{11,12} neuromuscular inefficiency,¹³⁻¹⁵ and reduced functional reserve throughout the span of adulthood. Along with the hallmark of motor impairments, pronounced sedentary behavior and fitness deficits that occur in CP¹⁶ have prompted concerns related to exaggerated cardiometabolic health risks.^{4,17,18} These issues highlight the importance of habitual physical activity among individuals with CP, and indicate a greater need to maintain physical fitness than even the general population, to offset the inevitable declines that accompany the natural aging process.

Although several studies^{19,20} have suggested a beneficial role for exercise participation among adults with CP, implementing physical activity programs for this population involves several physical and psychosocial challenges.²¹ Most adults with CP do not exercise regularly enough to maintain strength, which is a primary contributing factor for losses of function. Barriers include chronic pain, fatigue, limited transportation, and access to equipment and facilities.^{22,23} While exercise-induced exertion may indeed lead to a transient

increase in pain for individuals with CP, regular/habitual participation in activity and movement may serve to decrease self-reported average levels of pain.²⁴ If patients with CP are able to access exercise facilities regularly, multimodality exercise programs are suggested to be beneficial for preserving muscle morphology and strength, as well as gross motor function.²⁵ Such improvements, particularly for wheelchair users, can be of great significance in everyday activities and may be a useful means to improve strength and manage pain.²⁶

Regular exercise can also be an important factor in maintaining cardiovascular health and preventing disease. Indeed, mortality records have demonstrated a 2- to 3-fold greater death rate from coronary heart disease among adults with CP as compared with the general population.²⁷ Presently, there are no national surveillance programs that monitor patients with CP longitudinally; however, recent cross-sectional data demonstrate that overweight/obese adolescents with CP have a higher prevalence of dyslipidemia, hypertension, and fatigue than age- and weight-matched individuals without CP.²⁸ Thus, even small increases in physical activity may be more beneficial than previously thought. In fact, it has been recently demonstrated that individuals in the general population who engage in 150 minutes of moderate-intensity exercise per week have a 14% lower risk of developing coronary heart disease than those with no physical activity.²⁹ Even individuals who are physically active at lower than the recommended levels may have a significantly lower risk of developing coronary heart disease.

Although exercise is a vital part of health maintenance, there is limited research focusing on the impact of physical activity for simultaneous health and functional improvements in persons with CP. This is particularly an issue for patients with significantly compromised mobility (Gross Motor Function Classification System [GMFCS] III–V),³⁰ who face substantial barriers to exercise. Published exercise recommendations often encourage forms of exercise that are not appropriate for nonambulators or those who have great difficulty ambulating.³¹ Virtually no research has been conducted to assess the feasibility or efficacy of exercise protocols for individuals at these GMFCS levels, especially with regard to tolerance of exercise at doses known to stimulate fitness improvements. Therefore, the primary purpose of this study was to examine the feasibility of an exercise program among significantly motor-impaired adults with CP (ie, GMFCS III and IV), to determine whether a threshold level of cardiorespiratory stimulus (ie, at least 60% of age-predicted maximum heart rate) could be achieved without adverse effects such as significant postexercise pain.

Methods

Study design

Patients with CP (GMFCS III and IV) were recruited from the University of Michigan Adult Cerebral Palsy Clinic, Department of Physical Medicine and Rehabilitation. All clinical assessments were conducted in a single session, and included tests of anthropometric characteristics, exercise-stimulated cardiorespiratory parameters, and exercise-induced, patient-reported fatigue and pain experiences. Data from 11 patients with GMFCS III and IV were eligible for inclusion in these analyses. Approval to conduct this study was received by the institutional review board for research with human subjects.

Patient population

The sample consisted of 8 men and 3 women recruited by physicians and researchers with flyers, and from other respondents who had already volunteered to participate. To be eligible, participants had to be previously sedentary and older than 18 years, have a diagnosis of CP (GMFCS III or IV) with significantly limited mobility, be able to communicate (even with a communication device), and be able to follow basic instructions. Individuals with a history of cardiac problems were excluded from the study. Participants were not excluded for asthma, arthritis, or other joint deformities. Written consent was obtained from each participant or legal guardian.

GMFCS levels

The GMFCS levels assess activity limitations for gross motor function with a 5-level ordinal grading scale.³² Specifically, the GMFCS describes gross motor function of individuals with CP on the basis of self-initiated movement and with an emphasis on sitting, walking, and wheeled mobility. Distinctions between levels are also based on the need for assistive technology, including hand-held mobility devices (walkers, crutches, etc) or wheeled mobility. Individuals at “level I” can generally walk without significant restrictions, but may experience limitations in advanced motor-related skills. Conversely, individuals at “level V” are usually very restricted in their ability to function, even with external assistive technology. Individuals at level III are able to ambulate with an assistive device such as crutches or a walker. However, this level has a great deal of variability³³ related to functional ambulation for a given individual. For this study, subjects were chosen from the “less functional” available sample of level III patients, so as to include only individuals with significant impairment. These subjects were able to walk with walkers but at very low speed and gait efficiency (as determined via clinical assessment of gait), and they used wheelchairs for longer distances. Individuals at level IV are generally nonambulatory, although they sometimes can walk short distances with walkers. Studies of the GMFCS in the adult population show it to be reliable (intraclass correlation coefficient = .93)³⁴ and have interrater reliability (quadratic κ value of .978).² To preserve reliability, all patients were examined by the same physician investigator to classify GMFCS level.

Materials and measures

Anthropometric measures—As a part of normal medical intake, each patient was assessed for body mass (kg), height (cm), and body mass index (BMI; kg/m²). Since most patients had difficulty standing erect, supine recumbent length (cm) was measured and used instead to calculate height. Waist circumference (WC) and hip circumference (HC) were measured using a standard flexible anthropometric tape measure and evaluated to the nearest 0.1cm. For WC, a horizontal measure was taken at the narrowest part of the torso (ie, below xiphoid process and above the umbilicus). For HC, horizontal measures were taken at the site of maximal circumference. Waist-to-hip ratio was also calculated.

Cardiorespiratory parameters—Baseline measurements of heart rate and blood pressure (BP) were obtained before beginning exercise. A Polar heart rate monitor^a was placed on each participant, and oxygen consumption ($\dot{V} O_2$) measurements were obtained

using a Cosmed K4b² portable metabolic cart.^b This device provides real-time cardiorespiratory data including $\dot{V} O_2$ and carbon dioxide production. The portable analyzers and batteries of the metabolic unit were connected to a harness that was affixed to the back of the NuStep apparatus seat^c (fig 1). The flowmeter was attached to a mouthpiece that was worn on each participant's face, and covering both the nose and mouth. The analyzers of the metabolic unit were calibrated using verified concentrations of gases. Every 5 minutes during the bout of exercise, heart rate, $\dot{V} O_2$, steps per minute, watts, and respiratory exchange ratio (RER) were recorded. Every 10 minutes during the bout of exercise, each participant's BP was recorded. Heart rate and BP measurements were again taken at various time points postexercise, before participants were able to leave the laboratory, for safety purposes.

Exercise protocol—Participants were given instructions for all testing by a trained exercise physiologist and other support staff who had experience working with individuals with physical disabilities. For the morning of testing, participants were instructed to wear comfortable clothing and shoes conducive to performing physical activity; to refrain from consuming caffeine or other stimulating drinks; to have adequate sleep the night prior; and to avoid eating within 2 hours of the scheduled testing. Individuals were also familiarized with the experimental environment. After anthropometric testing was completed, participants were escorted to the physical activity laboratory and given basic preliminary instructions regarding the NuStep Recumbent Stepper^c and testing procedures. Foot straps and a seatbelt were fastened for safety, along with leg straps if necessary. The NuStep apparatus provides a seated, arm and leg flexion/extension exercise modality, against graded intensities. Footplates move forward and backward in a reciprocal knee and hip flexion/extension coupled pattern. Handles are attached to the foot pedals to allow for coupled dynamic action (ie, movement of the handles provides assistance to movements of the lower extremities, and vice versa). Ten intensity settings are available, as are an electronic step rate meter and step counter.

Participants were read a standardized script informing them about the exercise protocol and were instructed to exercise at a comfortable pace for 40 minutes with the option to take a break for any reason if necessary. All participants engaged in a 5-minute warmup at the lowest intensity setting available on the NuStep. This allowed participants to start increasing heart rate and become comfortable on the apparatus. At the start of the 40-minute bout, the intensity was increased by 1 level for all participants. Every 5 minutes, verbal encouragement was provided, and participants were asked to rate perceived exertion (ie, using a standard 6–20 Borg Ratings of Perceived Exertion [RPE] Scale³⁵). If the RPE value was 17 or higher, participants were given the option to go up a level and increase the resistance, go down a level, or remain at the same level of resistance. If the RPE value was less than 17, participants were asked whether they felt well enough to increase the resistance to the next level. If participants agreed, the level of resistance (ie, intensity) was then increased by a single increment.

Although every participant completed the exercise protocol, 4 individuals requested to take a break during the exercise because of restroom needs, fatigue, or difficulties with the

facemask placement. During each break, the mask was removed and the needs of the participant were addressed. Of the 4 needing breaks, 1 person needed 2 breaks. The average break time was approximately 6 minutes. The average time into the assessment when a break was requested was 16 minutes 20 seconds. During the breaks, the timer continued, and at 40 minutes the cooldown session started. Therefore, each participant took 40 minutes to complete the exercise protocol, regardless of rest breaks. At 1-minute intervals during the break, participants were asked to continue the exercise if they felt well enough to do so. All participants chose to resume exercise and finish the session. After completing the exercise, participants were provided a light snack and were asked to complete a postexercise questionnaire regarding levels of pain and discomfort. Considering the previously sedentary nature of these participants, it was deemed important to monitor postexercise cardiovascular response and recovery. Specific guidelines from the American Heart Association³⁶ and the American College of Sports Medicine³⁷ were followed for postexercise subject release. However, rather than merely waiting the recommended 6 to 8 minutes, “or until BP, heart rate, and ST segments were approximate to baseline values,”^{36(p1701)} participants in this study were monitored and released only after each person had reached full recovery (ie, rather than using an absolute timeline or percent recovery for each subject, complete recovery of heart rate and BP was required, regardless of time).

Pain—Pain was measured at 3 separate times for each participant. Before the exercise protocol began, participants completed a questionnaire that included pain assessment. They were asked to rank “best pain” (ie, least pain), “worst pain,” and the “average pain” over the last 3 months using a 10-point Likert scale ranging from 0 (representing no pain) to 10 (representing worst pain). Immediately after the exercise protocol, participants again completed the 10-point scale assessing “best pain,” “worst pain,” and the “average pain” they felt during the bout of exercise. All the individuals were then contacted via telephone the following day to inquire about their level of pain the night of the study, as well as their current level of pain, using the 10-point pain scale.

Statistical analysis

All statistical analyses were performed using SAS software version 9.3.^d Descriptive characteristics were stratified by GMFCS (ie, GMFCS III and IV) and are provided. Differences between the means of the GMFCS levels were determined for baseline characteristics and exercise-induced cardiorespiratory variables of interest by an independent-sample *t* test, and difference in proportions for sex and pain by the chi-square test. Bivariate analyses between all the variables were tested using a Pearson correlation. A stepwise logistic model was also fitted (ie, using the PROC LOGISTIC procedure in SAS^d) with various possible explanatory variables (ie, GMFCS, age, BMI, steps per minute, mean heart rate, mean RER, etc) to determine a best fit model for categorical pain during exercise, immediately after exercise, and 24 hours postexercise. Dummy coding was applied to the GMFCS variables (GMFCS III, 1; GMFCS IV, 0). Normality of the residuals was tested using a Shapiro-Wilk test, and homogeneity of the variance of the residuals was tested with standard regression diagnostics. Multicollinearity was tested using a variance inflation factor.

Results

Table 1 shows the descriptive characteristics of the sample members stratified by GMFCS. Significant differences were noted for various anthropometric variables including body mass, BMI, WC, and HC.

All participants completed the 40-minute exercise protocol; however, 4 participants requested to take a break during the study. Ten participants had a significant increase in $\dot{V} O_2$ from rest, and every participant had significantly elevated RER values throughout the exercise bout. Table 2 shows the exercise-induced cardiorespiratory characteristics of the entire sample and stratified by GMFCS. No differences were found in any exercise-induced cardiorespiratory parameter between subjects for GMFCS III and IV.

All participants were able to attain a significant increase in heart rate, with 5 exceeding the target threshold of 60% of their age-predicted maximum (fig 2). Of the 6 participants who did not achieve 60% of age-predicted maximum, 4 needed to take breaks during the exercise. Participants who reached 60% heart rate maximum demonstrated a trend of greater increases in $\dot{V} O_2$ and higher RER, as compared with those who did not reach the 60% heart rate range; however, these results were not significant. Energy expenditure was significantly increased from baseline, and during the course of the 40 minutes of exercise, represented a mean expenditure of approximately 115kcal.

Bivariate analyses

In the entire sample, age was significantly correlated with exercise heart rate response ($r = -.66$, $P < .05$), such that higher age was correlated to lower exercise-induced heart rate. Although there was a wide range of ages (ie, 23e62y), there were no differences in age between GMFCS III and IV. There were no significant correlations between any other subject-specific variables (eg, GMFCS, BMI) and exercise-induced cardiorespiratory outcomes. However, mean power output (ie, in watts) during exercise was significantly related to energy expenditure (ie, in kcal/min) ($r = .86$, $P < .001$).

Pain

Eight of the 11 participants reported feeling pain on a daily basis, before the study. Six participants reported pain during exercise; however, only 2 participants reported pain immediately after exercise, and only a single participant reported pain 24 hours postexercise. In the unadjusted and stepwise logistic regression models, no subject-specific or exercise-specific explanatory variables were found to predict pain during or after exercise.

Discussion

The primary finding of this study was a confirmation that among previously sedentary, significantly motor-impaired adults with CP, progressive aerobic physical activity can be performed without significant postexercise pain. This finding demonstrates the feasibility of the NuStep Recumbent Cross Trainer, or a similar device, as a viable modality to provide safe and effective physical activity in this population. While not every participant reached a threshold level of cardiorespiratory stimulus to induce an aerobic adaptive response (ie,

improved maximum $\dot{V} O_2$), all participants were indeed able to complete the entire session with a significant elevation in heart rate, RER, and energy expenditure. Considering the extent of physical inactivity among individuals with CP,³⁸ this is an important first step in identifying optimal exercise prescription strategies for cardiometabolic health in this population.

Fundamental movement proficiency among children with CP is negatively associated with sedentary behavior and positively associated with progressive physical activity.³⁹ Thus, preservation of functional capacity through adolescence and young adulthood is vitally important to ensure sustainable activity and participation. Sedentary behavior, defined as time spent sitting or lying down,⁴⁰ is known to be exaggerated in CP.³⁸ Sedentary behavior is not synonymous with diminished physical activity, as these factors are each independently associated with diabetogenic and atherogenic profiles.⁴¹⁻⁴³ Rather, it reflects a range of behaviors that coincide with an energy expenditure less than or equal to 1.5 times metabolic equivalents.⁴⁴ Many individuals with CP likely have significantly increased cardiometabolic risk because of the combination of insufficient physical activity and extended bouts of sedentary behavior. Even for individuals in the current study who did not reach 60% of heart rate maximum, every participant sustained significant increases in energy expenditure well above the sedentary behavior threshold. Clearly, the associated outcomes of functional deficit and chronic sedentary behavior may serve as contributing risk factors for other chronic disease processes (eg, the metabolic syndrome⁴⁵). Therefore, a simplistic and yet central preventive strategy from a clinical context is to encourage a lifestyle characterized by increasingly fragmented sedentary behavior. This investigation has effectively revealed the value of recumbent stepping using the NuStep to serve as a feasible tool for progressive aerobic exercise, intermittent physical activity accumulation, or both, in low-functioning adults with CP. However, since this is not a method of reducing sedentary behavior per se, there is still a critical need for future research to identify viable combinations of physical activity or exercise, and reduction of sedentary lifestyles in this population.

Study limitations

Given the nature of this pilot/feasibility project, a limited number of participants were recruited for assessment. Despite this limitation, all participants were able to complete the bout of exercise without any noted complications or latent self-reported pain.

Conclusions

Since there were no significant differences in exercise capacity or exercise-induced cardiorespiratory outcomes between participants with GMFCS III and IV, clinicians and therapists should feel comfortable recommending this exercise modality in CP. Future research is needed to determine the longitudinal efficacy of recumbent stepping exercise interventions in this population, as well as to identify optimal interventions (eg, multimodality and dose-response physical activity strategies for various levels of motor impairment) for improving quality of life and preventing secondary muscle pathology and cardiometabolic comorbidity in CP.

List of abbreviations

BMI	body mass index
BP	blood pressure
CP	cerebral palsy
GMFCS	Gross Motor Function Classification System
HC	hip circumference
RER	respiratory exchange ratio
RPE	rating of perceived exertion
$\dot{V} O_2$	[volume of] oxygen consumption
WC	waist circumference

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Fig 1.
The NuStep apparatus with Cosmed K4b² portable metabolic cart.

Fig 2.
Nearly half of participants were able to reach 60% heart rate maximum (highlighted with gray box).

Table 1

Participant descriptive information for all subjects, and stratified by the GMFCS

Characteristics	Total Sample	GMFCS III	GMFCS IV	P
N	11	7	4	
Women (%)	7	87.5	25.0	.02 *
Age (y)	36.00±13.00	36.43±10.91	35.25±18.01	.89
Body mass (kg)	73.79±19.45	82.70±19.09	58.20±4.73	.01 *
Recumbent length (cm)	161.36±10.18	159.00±8.83	165.50±12.40	.33
BMI (kg/m ²)	28.87±9.41	32.99±9.10	21.67±4.52	.04 *
WC (cm)	92.55±23.12	104.43±18.56	71.75±13.67	.01 *
HC (cm)	108.82±20.89	118.71±20.16	91.50±3.70	.01 *
Waist-to-hip ratio	0.85±0.10	0.88±0.06	0.78±0.13	.11
Resting systolic BP (mmHg)	126.36±6.08	124.00±4.27	130.50±6.54	.11
Resting diastolic BP (mmHg)	71.45±6.33	69.43±5.62	75.00±5.92	.19
Resting energy expenditure (kcal/min)	1.58±0.47	1.51±0.44	1.70±0.55	.55
Resting HR (beats·min ⁻¹)	80.00±17.11	78.00±13.05	83.50±24.69	.63

NOTE. Values are mean ± SD or as otherwise indicated.

* Significant difference between GMFCS III and IV ($P<.05$).

Table 2

Exercise-specific performance variables and exercise-induced cardiorespiratory outcomes

Variables	Total Sample	GMFCS III	GMFCS IV
Exercise steps per minute	79.06±24.61	80.34±24.26	76.08±30.67
Predicted HRmax (beats/min)	184.00±13.00	183.57±10.91	184.75±18.01
Mean exercise HR (bpm)	105.67±14.11 [*]	103.30±10.43 [*]	109.81 (20.25) [*]
Percentage of HRmax	57.35±5.6	56.30±4.85	59.2±7.10
Mean $\dot{V}O_2$ (mL · kg ⁻¹ · min ⁻¹)	8.26±3.13 [*]	7.52±1.28 [*]	9.56±5.08 [*]
Mean RER	0.94±0.07 [*]	0.93±0.07 [*]	0.96±0.08 [*]
Mean power (W)	16.21±8.1	17.44±4.20	14.47±12.14
Energy expenditure (kcal/min)	2.82±0.90 [*]	2.84±0.34 [*]	2.78±1.58 [*]
Pain during exercise (%) [†]	55 [*]	57 [*]	50 [*]

NOTE. Values are mean ± SD or as otherwise indicated.

Abbreviation: HRmax, maximum HR.

^{*} Significant increase from baseline (ie, preexercise) values at $P<.05$.[†] Percentage of participants who reported pain.