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Original Article

Functional community ambulation requirements in incomplete spinal cord injured subjects

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Study design: A group of people with incomplete spinal cord injuries (SCI) were evaluated and compared with able-bodied individuals during several walking conditions.
Objectives: To evaluate the functional community ambulation and estimated energy expenditure in persons with incomplete SCI and able-bodied individuals.
Methods: A list of criteria was used to evaluate functional community ambulation among participants. Physiological variables, such as the heart rate, oxygen uptake and the lactate concentration, were also measured.
Results: Three of nine incomplete SCI subjects and all able-bodied subjects were able to meet all the criteria measured. The required velocity to safely cross an intersection was the criterion that the incomplete SCI group had the most difficulty reaching. The able-bodied subjects had a comfortable walking velocity twice that of the incomplete SCI subjects' preferred velocity. When walking at the same velocity (incomplete SCI subjects' preferred velocity), the incomplete SCI subjects had a rate of oxygen uptake 26% greater than the healthy subjects and were 200% less efficient. The lactate concentration also proved to be a useful tool when evaluating the incomplete SCI subjects' walking efficiency. The incomplete SCI subjects lactate concentration increased after walking at their preferred velocity, meaning that the anaerobic pathways were used to meet energy demands.
Conclusion: Rehabilitation centers should adapt their evaluation forms and increase their criteria requirements to more suitable criteria that are found in the SCI patient's community. The physiological cost should also be taken into consideration when evaluating the SCI patient's functional ambulation.
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Keywords: spinal cord injury; walking velocity; oxygen uptake; community ambulator

Introduction

A spinal cord injury (SCI) resulting in paraplegia is one of the most devasting conditions a person can experience.[1] There are approximately 183 000 to 230 000 persons in the United States with SCI,[2] with the greatest number occurring in males between the ages of 16–30 years.[3] One of the most common concerns found in these patients is whether or not they will be able to walk again. With advances in technology and therapeutic strategies, ambulation after SCI is becoming more common everyday. Significant achievements have been made in the enhancement of ambulation in persons with incomplete SCI using various orthoses and assistive devices,[4] medication, locomotor training with weight support and functional electrical stimulation.[5,6] According to Tang *et al*[4] approximately one-third of all SCI patients become functional ambulators with 1 year after the incident. However, the quality and method of mobility adopted vary from one patient to another. Many factors influence ambulatory potential, such as the patient's level of conditioning, conditioning potential, motivation, severity of paralysis,[7] age and medical condition.[8]

Most evaluation forms used to assess a patient's functional progress during their rehabilitation program include a section pertaining to ambulation skills. Unfortunately, very few include community ambulation skills such as crossing streets with traffic lights, shopping, walking at specified velocities, and walking long distances.[9] The longest distance a patient is required to walk, according to the evaluation sheets found, is 200 feet (Texas Institute for Rehabilitation and

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Research) and the fastest velocity is 0.3 $m \cdot s^{-1}$ (Rancho Los Amigos Hospital Physical Therapy Department). Ramps required to ascend and descend varied in grade (10° to 20°) from one form to the next. Only two of the evaluation forms found included a section that required a patient to ascend and descend curbs (Texas Rehabilitation Hospital & Texas Institute for Rehabilitation and Research). All of these criteria were well below that which is needed to ambulate in a community. Nevertheless, patients with SCI are being discharged and classified as independent community ambulators. According to Stauffer,[10] community walkers are patients who are able to get themselves out of a wheelchair or bed and walk for a reasonable distance in and out of their homes unassisted by another person. They may use crutches or braces and a wheelchair for exceptionally long distances. In agreement with Robinett *et al*[9] it is believed that rehabilitation centers should establish suitable criteria for functional ambulation to more adequately represent the requirements for independence within their community.

To date, relatively little work has been reported on the gait characteristics of urban pedestrians.[11] The most danger that pedestrians encounter is when crossing intersections. Currently, pedestrian clearance intervals at intersections are calculated based on the normal walking velocity of 1.22 $m \cdot s^{-1}$.[12] The comfortable walking velocity for persons with SCI ranges from 0.21 $m \cdot s^{-1}$ to 0.69 $m \cdot s^{-1}$.[1,7,13–15] Adequate walking velocity is only one criterion that should be met for a person to be considered an independent community ambulator. According to Lerner-Frankiel *et al*[16] a community ambulator should be able to walk a distance sufficient to conduct business in a variety of locations, be able to ascend and descend curbs, as well as cross a street within the time provided by a crossing signal. Robinett *et al*[9] suggest that these criteria should be a set value for patients of all ages and who intend to return to an independent active life after rehabilitation. Two other important criteria that were not included in these studies are the ability to ascend and descend ramps and the ability to stop suddenly. There is a significant difference in walking pattern (velocity, cadence and step length) between walking on a leveled surface and walking up or down a sloped surface.[11] As for stopping suddenly, falls or collisions may occur while walking when an unexpected stop is needed, such as when a moving vehicle suddenly crosses the gait path, but the person walking does not have the ability to make that stop within the time available.[17]

The energy cost of patients with SCI is an additional issue that has yet to be evaluated in conjunction with the previously mentioned criteria. Even if a patient meets all the required criteria, it does not necessarily make for an efficient community ambulator. Previous studies have demonstrated that the energy expenditure of walking after SCI is above normal.[7,13–15,18–20] Energy expenditure is required to determine walking efficiency and should definitely be considered when evaluating a patient's functional independence.

The purpose of the study was to evaluate the functional community ambulation and estimated energy expenditure in persons with incomplete SCI and able-bodied individuals.

Methods

Subjects

Nine subjects suffering from an incomplete spinal cord injury (seven men and two women) and nine healthy adults (seven men and two women) were studied. The subjects with incomplete SCI had a mean age of 41.1 ± 10.1 years, height 1.72 ± 0.13 m, and weight 76.2 ± 19.2 kg. For the healthy adults, the mean age was 41.2 ± 9.3 years, height 1.70 ± 0.09 m, and weight 76.3 ± 13.3 kg. All of the spinal cord injured subjects had completed a rehabilitation program. Some subjects with incomplete SCI were on medications such as baclofen to reduce spasticity. Two subjects with incomplete SCI walked with functional electrical stimulation. The ambulatory ability for the subjects with incomplete SCI varied: two of them walked with canes, four with Canadian crutches and three without assistive device (Table 1). All subjects gave informed consent.

Criteria determination

Five criteria were selected to evaluate a person's community independence according to five criteria: (1) functional distance required to walk to conduct business (supermarkets, drugstores, banks, department stores, post offices and physician's offices); (2) velocity required for safe crossing at intersections; (3) ascend and descend curbs; (4) ascend and descend ramps and (5) ability to stop suddenly. The measurements of functional distance, velocity and curb height were selected according to previous work done by Lerner-Frankiel *et al*[16] and refined by Robinett *et al*[9] according to communities of different populations. Evaluation was based on the findings for communities with a population greater than 95 000.[9] The average curb height for such communities is 18.5 cm, while the average velocity required for safe crossing is 1.06 $m \cdot s^{-1}$. To determine the functional distance required for ambulation in these communities, the average of the furthest location was selected. The supermarket requires a person to walk 342.0 m. Robinett *et al*[9] measured this as the distance from the handicapped parking space or the space closest to the entrance of the supermarket, through the closest entrance, down half the total number of aisles, through the check out and back to the car.

The ramp used during evaluation followed city regulations with a slope of approximately 4.7°. To evaluate the ability to stop suddenly, we based our results on Cao *et al*[17] findings. They concluded that young healthy adults succeed in stopping suddenly when given an available response time of 750 ms.

Table 1 Demographic information on the incomplete SCI subjects

Code	*Age (years)*	*Sex*	*Level of lesion*	*Time since injury (years)*	*Time since discharge (years)*	*Ambulatory status*
1	40	M	T8	11.5	10.75	Independent
2	53	F	C5–C7	8.5	7.75	2 Canadian crutches
3	44	M	C6–C7	19.5	19	2 Canadian crutches
4	36	M	C3–C4	12	11.75	2 Canadian crutches
5	33	M	C5–C7	12.5	11.5	2 Canadian crutches
6	54	F	C5–C7	2	1.5	Independent
7	22	M	C7–T1	6.5	6	2 Canes
8	47	M	C4	5.5	4.5	2 Canes
9	41	M	C3–C4	3.25	2.5	Independent

All subjects are classified as ASIA Grade D[21]

Apparatus

The subjects walked on a 6 m long pathway providing the recording of at least five walking cycles. The subject's shoes were instrumented with pressure switches (Interlink Electronics, California, USA) placed under the heel and toe of each foot. These contacts were digitally coded to provided accurate temporal values corresponding to the onset and offset of right and left single-support and double-support phases. The horizontal foot displacement of both feet were recorded using a modified version of Bessou's *et al*[22] locometer. Small monofilament wires were attached to the back of each shoe. The locometer consists of four pairs of pulleys (3.5 cm diameter) which reduce the displacements of a modifiable resistance (a 1 kg weight was used in our study). This resistance is attached to a thick wire that is wrapped around a 22 cm wheel fixed at the top of the locometer. This low resistance served only to prevent the wires from shivering: It did not affect the walking and was not perceived by the subject. A ten turn high precision potentiometer was mounted at the bottom of the locometer and provided a voltage proportional to the distance covered. The system provided a resolution of 3 mm.

Oxygen uptake was conducted using a Ventilation Measurement Module (Vacu-Med: Cat.#VMM-401). Gas samples were analyzed for oxygen and carbon dioxide content (Applied Electrochemistry Inc., Sunnyvale, USA). All gas volumes were corrected to standard values of temperature, saturation, and pressure (STPD). The gas analyzers and the Ventilation Measurement Module were mounted onto a trolley. This setup allowed the evaluator to push the gas analyzers with ease and follow the subjects during walking trials. The subject's heart rate was monitored with a Polar Vantage NV heart rate monitor and stored data was transmitted to a PC with a Polar Advantage Interface. The subject's lactate concentration was analyzed with an Accusport portable lactate analyzer (Sports Resource Group Inc.).

Procedure

The functional evaluation was conducted in two sessions: (1) Criteria evaluation, and (2) Energy expenditure. These sessions were taken in the same day with proper rest allotted to each subject in between evaluations.

Criteria evaluation After being accustomed to walking with the foot contacts the subjects were asked to walk at their preferred and then maximum velocity. Each task consisted of 3–5 trials, depending on the subject's capacities. The subjects were than asked to ascend and descend a platform that resembled the measurements of a typical street curb (height: 18.5 cm × length: 4 feet × width: 5 feet) followed by ascending and descending a ramp constructed according to city regulations (4.7°). Each task was performed 3–5 times. For the final task, the subjects were asked to stop as quickly as possible, from their preferred walking velocity, in response to an auditory stimulus (beep of 50 ms in duration). The reaction time was taken between the appearance of the stimulus and the moment when the subject stopped walking with both feet stable (double support phase). The stimuli were randomly presented at the onset of either the first, third or fifth walking cycle. Two catch trials (without stimulus) served to prevent anticipation (8–12 trials). Signals from the foot contacts were sampled at 300 Hz. Adequate resting periods were given relative to the subject's condition.

Energy expenditure Oxygen uptake and heart rate were measured at rest, walking at preferred velocity, and SCI subjects walking at maximum velocity and able bodied subjects walking at SCI preferred velocity. Each of these trials lasted 3 min. For the latter two tasks, the subjects walked around a rectangular pathway marked on the laboratory floor (5.5 m × 3.5 m). Lactate concentrations were measured before the walking trials and after the subjects walked at their preferred velocity. A 5 min rest was given between each trial. During the initial resting trial, subjects were seated and asked to relax. The oxygen uptake, CO_2 and O_2 concentrations were sampled breath by breath at 20 Hz and the heart rate was stored in the heart rate monitor at 15 s intervals.

The physiological variables measured to estimate the energy expenditure during walking were expressed by three different parameters. The VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$) was used to measure the power requirement.[7] The physiological cost was examined through oxygen cost per meter ($ml \cdot kg^{-1} \cdot m^{-1}$) and the number of heart beats per meter ($beats \cdot m^{-1}$).

The results for the velocities and the lactate concentrations were submitted to an ANOVA with repeated measures. The results for the heart rate, oxygen uptake, O_2 cost and heart rate cost were subjected to a MANOVA with repeated measures. The level of significance was set at $P<0.05$.

Results

Criteria

The number of incomplete SCI subjects who met the criteria is summarized in Table 2. All of the healthy subjects met the criteria. However, only one incomplete SCI subject met all the criteria. Two incomplete SCI subjects met all of the criteria except for walking velocity. They were able to meet the velocity criteria of 1.06 $m \cdot s^{-1}$ only when walking at their maximum velocity. The average comfortable walking velocity was 0.643 $m \cdot s^{-1}$for the incomplete SCI subjects and 1.416 ± 0.124 $m \cdot s^{-1}$ for the healthy subjects. The average maximum walking velocity was 0.857 ± 0.611 $m \cdot s^{-1}$ for the incomplete SCI subjects and 2.176 ± 0.321 $m \cdot s^{-1}$ for the healthy subjects. The incomplete SCI subjects were more successful with the other criteria. Two incomplete SCI subjects could not ascend or descend a curb or a ramp and could not walk the required distance (342 m). However, all incomplete SCI subjects stopped walking in the allotted time (750 ms).

Estimation of energy expenditure

Physiological variables among the incomplete SCI subjects were examined. Figure 1 illustrates the walking velocities of all subjects during physiological cost evaluation. These velocities are different from the velocities in the first evaluation session due to the equipment worn by the subject. Both groups were asked to walk under two specific conditions (Matched and No Matched). For the Matched condition, the incomplete SCI subjects walked at a comfortable velocity and the healthy subjects were asked to walk at that same velocity. For the No Matched condition, the incomplete SCI subjects were asked to walk at a maximum velocity and the healthy subjects walked at their preferred velocity. Velocities were subjected to a Group (2) by Condition (2) ANOVA with repeated measures on the condition factor. The main effect of Group ($F(1,16)=1.14$, $P>0.05$) was not significant. The main effect of Condition ($F(1,16)=88.45$, $P<0.01$) and the interaction of Group by Condition ($F(1,16)=17.35$, $P<0.01$) were significant. The SCI's comfortable walking velocity was successfully matched. The health subjects' comfortable walking velocity was

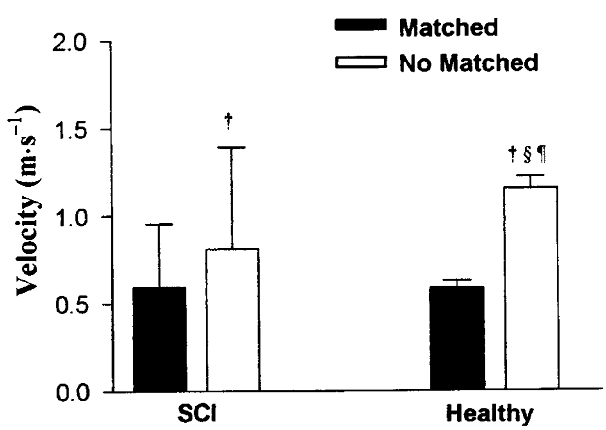

Figure 1 Walking velocities of SCI and Healthy subjects for different experimental conditions: Matched = SCI and Healthy subjects walking at SCI comfortable velocity, No Matched = SCI walking at a maximum velocity and Healthy subjects walking at a comfortable velocity. †Indicates significant difference ($P<0.01$) with Matched (SCI). §Indicates significant difference ($P<0.01$) with No Matched (SCI). ¶Indicates significant difference ($P<0.01$) with Matched (Healthy subjects)

Table 2 Results of walking test among incomplete SCI subjects

Code	*Comfortable velocity* (1.06 $m \cdot s^{-1}$)*	*Maximum velocity* (1.06 $m \cdot s^{-1}$)*	*Distance* (340 m)*	*Curb* (18.5 cm)*	*Ramp* (4.7°)*	*Sudden stop* (750 ms)*
1	0.924	1.609	340	a/d	a/d	506
2	0.529	0.551	340	a/d	a/d	656
3	0.467	0.703	340	a/d	a/d	684
4	0.194	0.273	56.9	unable	unable	0**
5	0.394	0.507	340	a/d	a/d	0**
6	0.897	1.163	340	a/d	a/d	446
7	0.494	0.806	340	a/d	a/d	655
8	0.129	0.14	35	unable	unable	0**
9	1.755	1.965	340	a/d	a/d	433

*Values represent the criteria for its specific parameter. **SCI Subjects were already in a static position when the stimulus was introduced. a/d = ascend and descend significantly faster than the incomplete SCI subject's comfortable and maximal velocity ($P<0.01$). This analysis also revealed that the incomplete SCI subjects' maximal walking velocity was significantly faster than their comfortable walking velocity ($P<0.01$).

Figure 2 illustrates lactate concentration, heart rate and oxygen uptake of all subjects for the different experimental conditions. Lactate concentration data were submitted to a Group (2) by Condition (2) ANOVA with repeated measures on the condition factor. The ANOVA revealed no significant main effect of Group ($F(1,16)=0.90$, $P<0.05$), a significant effect of Condition ($F(1,16)=23.16$, $P<0.01$) and a significant interaction Group by Condition ($F(1,16)=5.01$, $P<0.05$). The decomposition of this interaction into main effects (Newmans-Keuls) revealed that persons with incomplete SCI had a greater lactate accumulation than healthy subjects when walking at their comfortable velocity ($P<0.01$). This analysis also revealed that lactate concentrations were significantly higher during walking in comparison with resting concentrations for incomplete SCI subjects ($P<0.01$) while no significant differences were found for healthy subjects between resting and walking conditions ($P>0.05$).

Heart rate (beats·min^{-1}) and oxygen uptake (ml·kg^{-1}·min^{-1} were measured at rest, when walking at a matched velocity and when walking at a maximum velocity for the patients and at a preferential velocity for the able-bodied subjects. Data were submitted to a Group (2) by Condition (3) MANOVA with repeated measures on the condition factor. The MANOVA revealed a significant main effect of Group ($F(2,15)=13.12$, $P<0.01$, Wilk's lambda$=0.364$), significant effect of Condition ($F(4,13)=63.77$, $P<0.01$, Wilk's lambda$=0.0484$) and a significant interaction Group by Condition ($F(4,13)=5.16$, $P<0.01$, Walk's lambda$=0.386$). The decomposition of the interaction into main effects (Newman-Keuls)

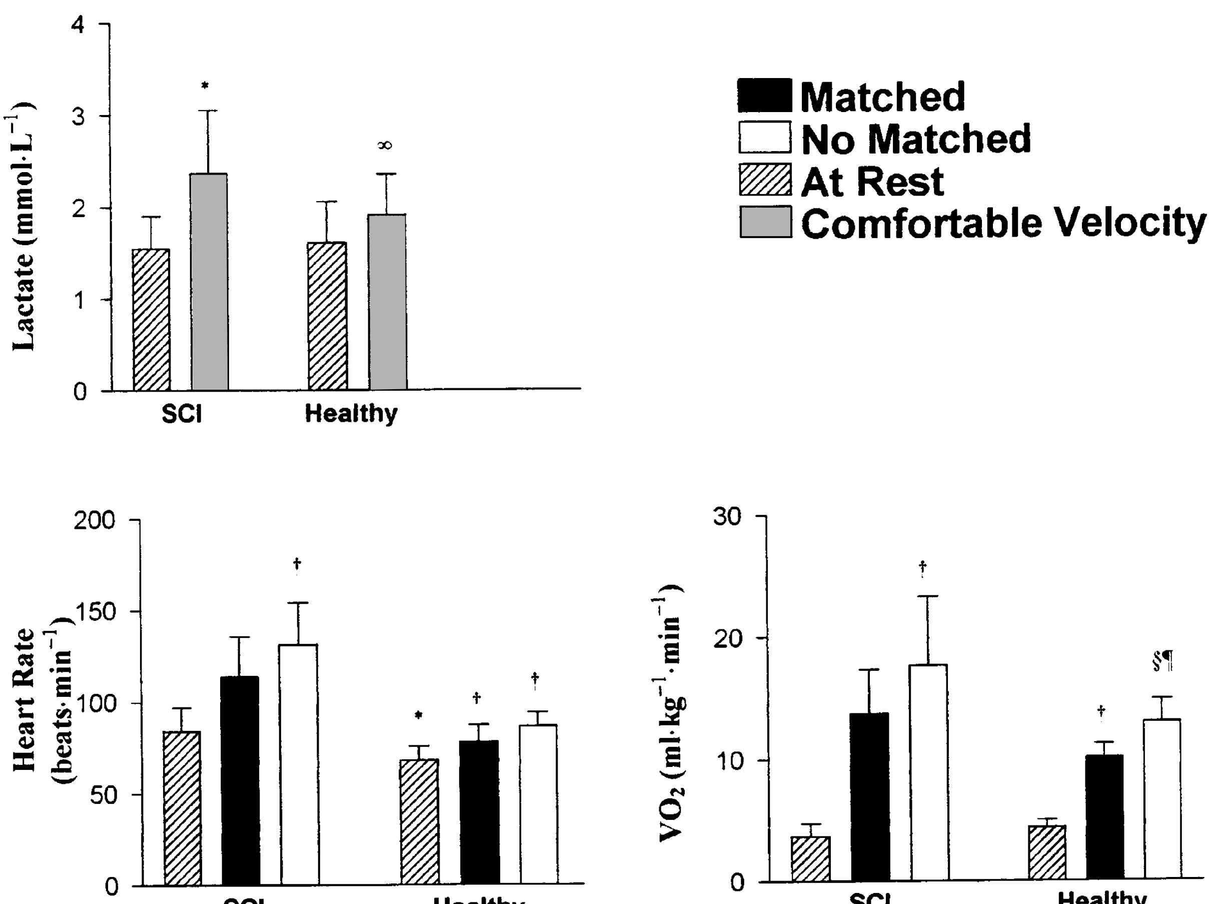

Figure 2 Lactate concentration, heart rate and oxygen uptake of SCI and Healthy subjects for different experimental conditions: Matched = SCI and Healthy subjects walking at SCI comfortable velocity. No Matched = SCI walking at a maximum velocity and Healthy subjects walking at a comfortable velocity. At Rest = SCI and Healthy subjects at rest and Comfortable Velocity = SCI and Healthy subjects walking at a comfortable velocity. *Indicates significant difference ($P<0.01$) with At Rest (SCI). ∞Indicates significant difference ($P<0.01$) with Comfortable Velocity (SCI). †Indicates significant difference ($P<0.01$) with Matched (SCI). §Indicates significant difference ($P<0.01$) with No Matched (SCI). ¶Indicates significant difference ($P<0.01$) with Matched (Healthy subjects)

for the heart rate variable revealed that when both groups (SCI and able-bodied) walked at the same velocity (SCI's preferred velocity) the incomplete SCI subjects' heart rate was significantly higher ($P<0.01$). The analysis also revealed that persons with incomplete SCI had a higher heart rate at rest and under the Matched condition than healthy subjects under the same conditions ($P<0.01$). The incomplete SCI subjects also had a higher heart rate during maximum walking velocity in comparison to able-bodied subjects walking at a preferred velocity even though the healthy subjects were walking significantly faster (No Matched condition) ($P<0.01$). The decomposition of the interaction for the oxygen uptake revealed no significant differences between incomplete SCI subjects and healthy subjects at rest. Also oxygen uptake was significantly higher for both groups for the No Matched condition in comparison to the Matched condition. Furthermore, oxygen uptake was significantly lower for the able-bodied subjects for both walking conditions when compared to SCI subjects under the same conditions (Matched and No Matched conditions) ($P<0.01$).

Figure 3 illustrates the physiological cost expressed through oxygen uptake and heart rate of all subjects for different experimental conditions. Data were submitted to a Group (2) by Condition (2) MANOVA with repeated measures on the condition factor. The MANOVA revealed no significant main effects of Group ($F(2,15)=3.00$, $P<0.05$, Wilks's lambda $=0.714$), a significant effect of Condition ($F(2,15)=44.06$, $P<0.01$, Wilks's lambda $=0.145$) and a significant interaction Group by Condition ($F(2,15)=14.21$, $P<0.01$, Wilks's lambda $=0.345$). The decomposition of the interaction into main effects (Newman-Keuls) revealed that the incomplete SCI subjects were less efficient than healthy subjects (O_2 and HR cost) when both groups walk at the same velocity (SCI's preferred velocity) and when both groups walked at different velocities (SCI's maximum velocity and able-bodied subjects' preferred velocity) ($P<0.01$). The decomposition also revealed that the healthy subjects and the incomplete SCI subjects were more efficient (HR cost) when they walked at a faster velocity ($P<0.01$). However, the effect was greater in healthy subjects.

Discussion

The criterion that seemed the most difficult for incomplete SCI subjects to meet was the required velocity to safely cross an intersection. In a community of 95 000 persons or greater, community ambulators need to cross intersections at a velocity that is not far from a healthy persons' preferred walking velocity of 1.22 $m \cdot s^{-1}$.[12] According to the results, even with a maximum effort, six out of the nine incomplete SCI subjects evaluated are unable to safely cross an intersection. The results also indicate that the incomplete SCI subjects who had difficulties walking the required distance to conduct business also had problems ascending and descending a curb or a ramp. These subjects walked less than one sixth of the distance required. All of the subjects were able to stop in the allotted time. However, this was expected since most incomplete SCI subjects walked at a much slower preferred velocity than the able-bodied subjects. Two incomplete SCI subjects were almost motionless when the stimuli appeared due to such a slow walking velocity and they were able to stop without making any further steps (which explains their reaction time of 0 ms).

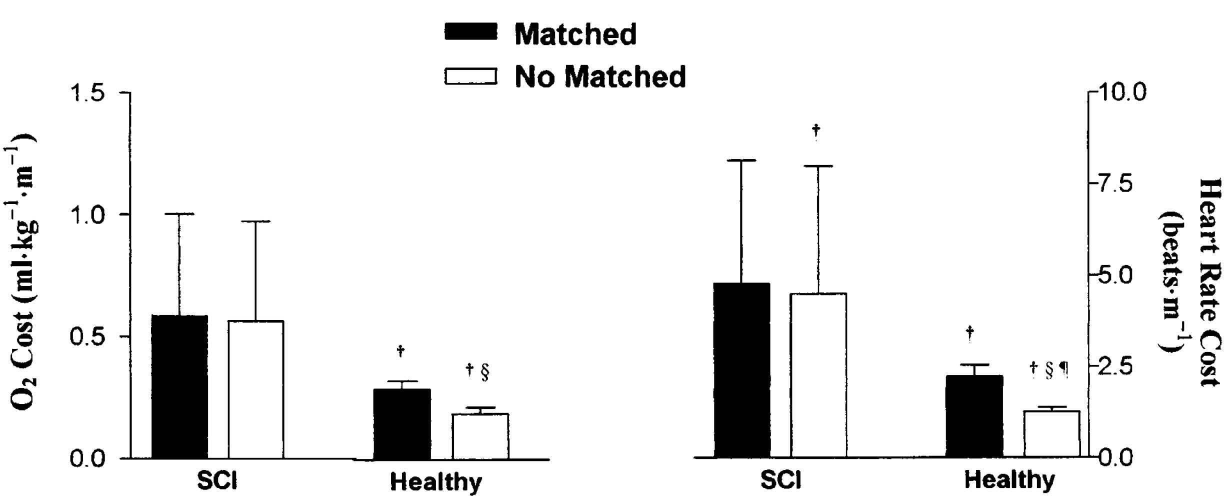

Figure 3 Physiological cost expressed through oxygen and heart rate of SCI and Healthy subjects for different experimental conditions: Matched = SCI and Healthy subjects walking at SCI comfortable velocity, No Matched = SCI walking at a maximum velocity and Healthy subjects walking at a comfortable velocity. †Indicates significant difference ($P<0.01$) with Matched (SCI). §Indicates significant difference ($P<0.01$) with No Matched (SCI). ¶Indicates significant difference ($P<0.01$) with Matched (Healthy subjects)

There also seemed to be a relationship between the incomplete SCI subjects' rate of success in meeting the criteria and the type of assistive device used. The SCI subjects who did not require any assistive device were able to walk at faster velocities in comparison with the SCI subjects who walked with either two Canadian crutches or two canes. There did not seem to be a difference between the SCI subjects who required two Canadian crutches to ambulate and the SCI subjects who walked with two canes. These results are similar to those found by Waters *et al.*[23] However, the Waters *et al.*[23] study revealed no significant difference in walking velocity between the SCI subjects who are accustomed to walk with a cane and the SCI subjects who walk with crutches.

Walking is physiologically stressful for the incomplete SCI subjects as suggested by Waters *et al.*[24] Several classification systems have been proposed (in terms of strenuousness) for rating sustained physical activity, such as walking., The physical activity ratio, or PAR, is a system that classifies work tasks by the ratio of energy required for the task to the resting energy requirement.[25] Light work for men is defined as that eliciting an oxygen uptake up to three times the resting requirement. For women, the work classifications are slightly lower owing to their generally lower aerobic capacities. As a frame of reference, most industrial jobs and household tasks require less than 3 times the resting energy expenditure.[26] When classifying the subjects exercise intensity for a preferred walking task using the PAR, the results indicated that the healthy subjects were working at a light level (PAR = 2.9), while the incomplete SCI subjects were working at a moderate level (PAR = 3.7).

When comparing both groups walking at the same velocity, it was found that the incomplete SCI subjects expended a greater amount of energy than the healthy subjects. The incomplete SCI subjects had a rate of oxygen uptake 26% greater and a heart rate 32% higher than the healthy subjects. Most studies compare physiological work between SCI subjects and healthy subjects while walking at their own preferred velocities. Nevertheless, the SCI subjects consume more energy than the healthy subjects when walking at their respected preferred velocity.[7,24] When analyzing the physiological costs, which is a better indicator of walking efficiency, the O_2 cost revealed that the incomplete SCI subjects were 2 times less efficient than the healthy subjects. The heart rate cost revealed similar results. The incomplete SCI subjects were 2.1 times less efficient than the healthy subjects.

A person is usually most efficient when they are walking at their preferred velocity. When comparing the physiological costs between the matched and preferred walking velocity in healthy subjects, results indicate that this group was more efficient when walking at their preferred velocity. The O_2 cost revealed that the healthy subjects were 1.5 times more efficient when walking at their preferred velocity, while the heart rate cost revealed that they were 1.8 times more efficient at their preferred velocity. Waters' *et al*[27] findings support the suggestion that healthy adults are more efficient when they walked at their preferred velocity (standard table). Also, the results from their study between the incomplete SCI subject's preferred and maximum walking velocity revealed to be different. There was no difference in efficiency according to O_2 cost, however, the heart rate cost revealed a slight difference in efficiency between the two velocities. The incomplete SCI subjects were slightly more efficient when walking at their maximum velocity. This finding suggests that rehabilitation centers should encourage and accustom SCI patients to walk faster than their preferred walking velocity. This form of exercise will improve the SCI patients' walking efficiency and will progressively increase the patients' preferred walking velocity.

When walking at their maximum velocity, the incomplete SCI subjects were still walking 30% slower than the healthy subjects walking at a comfortable velocity, yet the incomplete SCI subjects' rate of oxygen uptake was 27% greater. The results showed a similar outcome for the heart rate. The incomplete SCI subjects had a heart rate 34% higher than the healthy subjects. Even though their maximum velocity was approaching the required velocity for safe intersection crossing, it proved to be physically demanding for the incomplete SCI subjects. When analyzing the physiological cost, even greater differences were found between groups. The O_2 cost revealed that the incomplete SCI subjects were three times less efficient than the healthy subjects, while the heart rate cost revealed that the incomplete SCI subjects were 3.6 times less efficient.

The health subjects' lactate concentration did not significantly increase after walking at their preferred velocity. However, the incomplete SCI subjects' lactate concentration was 35% greater after walking at their preferred velocity. The lactate concentration is a great indicator of energy system distribution, aerobic (long term) or anaerobic (short term). At high exercise intensities there is an increase of lactate concentration and anaerobic pathways are increasingly used to meet energy demands.[28] Consequently, there is a decrease in the length of time that an activity can be sustained due to the restricted availability of anaerobic energy supply and the accumulation of lactate.[27] When prolonged exercise is performed at $<50\%$ of an individual's maximal aerobic capacity, such as walking, the aerobic metabolic pathways are sufficient to meet the energy demands of the muscle and the individual can sustain activity for a prolonged time period without exhaustion.[27] It can therefore be speculated that the aerobic system was activated during the walking trial and the healthy subjects were walking at $<50\%$ of their maximal aerobic capacity. However, it seems that the incomplete SCI patient's anaerobic pathways were used to accomplish the 3 min walking task. If so, the incomplete SCI subjects could not have continued walking much longer. Rehabilitation centers should pay more attention to the lactate concentration of their patients and make certain that aerobic pathways are being used during walking.

The velocities evaluated during the 'criteria' session are different from the velocities in the 'energy expenditure' session. The reason being that the subjects walked around a rectangular pathway for the latter session which caused them to reduce their speed when turning the corners. However, the difference in velocities had no effect on the estimation of energy expenditure.

It was not possible to establish norms on energy expenditure and walking velocities because of the small number of subjects evaluated in this study. Nevertheless, the findings in this study reveal that incomplete SCI subjects do not have the functional ambulation required to meet community criteria. A further study, using the same criteria, should be conducted with a greater number of subjects in order to establish proper norms.

Conclusion

The findings of this study suggest that rehabilitation centers need to take into consideration the required criteria for a community in which the incomplete SCI patients live. The definition of an independent community ambulator should be refined to include more realistic distances and walking velocities. The walking velocity was the criterion that most subjects (incomplete SCI) could not reach. When the subjects (incomplete SCI) walked at a maximum velocity, the rate of success was slightly higher. Consequently, the subjects' (incomplete SCI) estimated energy expenditure increased significantly at such maximal velocities. Therefore, it can be assumed that the incomplete SCI subjects could not continuously cross a series of intersections while walking at their maximal velocity. Rehabilitation centers should pay closer attention to the SCI patients' velocity and increase the standard for this criterion. Another suggestion would be to have city traffic engineers increase pedestrian's clearance intervals at intersections. This would slow down traffic and allow pedestrians, particularly those with gait disabilities and elders, to safely cross intersections without walking at their maximum velocity. However, the other criteria (distance, curb and ramp) would still need to be assessed by rehabilitation therapists before a SCI patient's discharge should be granted. Furthermore, physiological variables should be accounted for when evaluating the SCI patient's functional community ambulation.

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