Original Research Article

Neurorehabilitation and Neural Repair
2020, Vol. 34(4) 289–298

DOI: 10.1177/1545968320907076
journals.sagepub.com/home/nnr

Oxygen Cost During Walking in Individuals With Stroke: Hemiparesis Versus Cerebellar Ataxia

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Abstract

Background. Understanding the factors that limit mobility in stroke patients is fundamental for proposing appropriate rehabilitation strategies. A high oxygen cost during walking (Cw) has a strong impact on the community ambulation of hemiparetic patients. The Cw in poststroke cerebellar ataxia is poorly evaluated, unlike hemiparetic gait. *Objective*. To compare the oxygen cost/self-selected walking speed (S) relationship in stroke individuals with cerebellar ataxia or hemiparetic gait. *Methods*. Thirty-three subjects were included (14 cerebellar stroke, 19 hemispheric stroke), with stroke confirmed by brain imaging and able to walk without human assistance. We measured Cw using the Metamax3B. The relationship between Cw and self-selected walking speed was modelled by logistic regression and then compared between the cerebellar and hemispheric groups. *Results*. No significant difference was found between the 2 groups for all characteristics of the population, except motor impairments, spasticity, and ataxia ($P < .01$). We identified 2 separate Cw/S relationships with different logistic regression equations for the 2 groups. Faster than 0.4 $m\,s^{-1}$, Cw was 30.6% to 39.9% higher in patients with cerebellar stroke in comparison with hemispheric stroke individuals. The Cw was correlated with ataxia ($r = 0.88$; $P < .001$) in the cerebellar group, whereas there was a correlation with motor impairments ($r = -0.61$; $P < .01$), spasticity ($r = 0.59$; $P < .01$), and ataxia ($r = 0.81$; $P < .01$) in hemispheric stroke individuals. *Conclusion*. The Cw in poststroke cerebellar ataxia is significantly higher compared with hemiparetic patients at an equivalent walking speed. The impact on community walking needs to be explored in stroke survivors with cerebellar stroke.

Keywords

oxygen cost, walking, cerebellar stroke, hemispheric stroke, energy expenditure

Introduction

Walking is a meaningful activity in view of social participation and quality of life in individuals with poststroke sequelae.[1] Unfortunately, at 6 months after stroke, less than 30% of patients have regained the ability to walk independently, and almost 50% believe they have restricted mobility in the community.[2] The limitation of walking activity may be due to metabolic factors, because individuals with stroke suffer from significant cardiorespiratory deconditioning. The VO_2 peak in these patients was found to be 26% to 87% lower than that of age- and sex-matched healthy control subjects.[3] In addition, secondary to their neurological impairments, stroke individuals consume between 1.5 and 2 times more oxygen when walking than healthy subjects, which causes intense metabolic strain, leading to an increase in fatigability and consequently to limitation of activity.[4] The walking efficiency of an individual can be quantified by measuring the oxygen cost of walking (Cw), which is the consumption of oxygen per meter expressed in $mL\,kg^{-1}\,m^{-1}$.[5] The Cw is of crucial importance in stroke individuals, because this parameter is

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Supplementary material for this article is available on the *Neurorehabilitation & Neural Repair* website along with the online version of this article.

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associated with walking ability[4] and social participation.[6] Franceschini et al reported that stroke individuals with a Cw greater than 0.55 $mL\,kg^{-1}\,m^{-1}$ have walking restrictions for community activities.[6]

Neurological impairments following stroke depend on the damaged neurological structure. Thus, after a hemispheric stroke, damage to the pyramidal pathway is classically responsible for spastic hemiparesis, associated or not with cognitive, sensory, and neuro-vegetative impairments, depending on the extent of the injury. These impairments lead to a stiff knee gait and circumduction of the impaired lower limb.[7] After a cerebellar stroke, individuals typically have coordination and balance disorders, resulting in characteristic ataxic walking.[8]

Among these 2 types of clinical conditions, several deficiencies may induce an increase in Cw. The presence of co-contractions related to spasticity are associated with an increase in Cw.[9,10] The increase in the variability of the trajectories of the limb segments due to the loss of selectivity of the central control[11] is also associated with the increase in Cw.[9,12]

The gait patterns of cerebellar stroke and hemispheric stroke patients are very different. Cerebellar ataxic gait is typically characterized by an increased step width, variable foot placement, irregular foot trajectories, and a resulting unstable, stumbling walking path with very high movement variability and a high risk of falling. This type of gait is clinically recognizable and is easily differentiated from the gait pattern of hemiparetic individuals, who have a loss of symmetry, with a tendency for increased stance time on the unaffected limb. The affected lower limb appears stiff-legged, demonstrating a synergy pattern with extension, adduction, internal rotation of the hip, extension of the knee, and plantarflexion/inversion of the foot/ankle. This extended limb posture leads to an impairment of limb clearance during the swing phase, and compensatory maneuvers include hip hiking, lateral trunk sway, circumduction, and, less commonly, contralateral vaulting (Olney and Richards, 1996)[13]. In a previous study, we showed that the relationship between the Cw and self-selected walking speed (S) was strong in individuals with poststroke hemispheric sequelae ($r = -0.94$; $R^2 = 0.97$, $P < .001$).[14] We assumed from this work and our clinical experience that this strong relationship is explained by the fact that the walking pattern was similar from one hemiparetic individual to another. In addition, Zamparo et al, in a similar study, compared the Cw of 20 hemiparesis patients and 17 healthy subjects. The authors found different Cw/S relationships between the groups of subjects ($P < .001$ in the covariance analysis).[15]

The Cw/S relationship seems to be a characteristic of the walking efficiency of individuals that would be specific to the individual's walking pattern. To support this hypothesis, it must be compared with a very different gait pattern, that of ataxic individuals with post–cerebellar stroke. To our knowledge, no studies have explored the Cw of cerebellar stroke individuals or the Cw/S relationship.

The objective of this study was to compare the relationship between Cw and S in individuals with cerebellar and hemispheric stroke. Our hypothesis is that individuals with cerebellar stroke sequelae do not have the same Cw/S relationship as hemiparetic stroke individuals, due to the differences in impairments and gait patterns between these 2 stroke types. If this hypothesis is confirmed, this would imply that a specific Cw/S relationship could be identified for patients, depending on the stroke location.

Methods

Participant Selection

We recruited participants from November 2017 to November 2018. We recruited those with stroke sequelae from among the patients treated in the PRM department. All participants were required to be able to walk continuously for 6 minutes with or without mobility aids. We created 2 groups of participants during the recruitment process: the cerebellar stroke group included any individual with a single stroke in the cerebellum, as confirmed by magnetic resonance imaging (MRI), and the hemispheric stroke group included any individual with a single stroke in either cerebral hemisphere, as confirmed by MRI.

The exclusion criteria for both groups were the following: presence of acute cardiac or respiratory pathologies or decompensated chronic pathologies. The recruitment process is outlined in a flow chart (Figure 1).

The health professional responsible for the protocol informed the patients of the details of the protocol. Participant consent was obtained prior to data collection. The research protocol was accepted by an ethics committee, number: 2015-01-13-57.

Participant Evaluation

Motor function was evaluated using the Demeurisse Motricity Index.[16] This score is validated in stroke patients.[17] Spasticity was evaluated using the Modified Ashworth Scale.[18] Walking autonomy was assessed using the modified Functional Ambulation Classification.[19] Autonomy related to activities of daily living was evaluated using the Barthel Index.[20] Ataxia while standing and walking was assessed using the postural and walking sections of the International Cooperative Ataxia Rating Scale (ICARS).[21] We measured the walking speed from the distance achieved during a 6-minute walk test as S.[22] All evaluations were performed by the same examiner for all participants.

Equipment

Oxygen (O_2) consumption while walking was measured by indirect calorimetry using the Metamax3B breathing gas

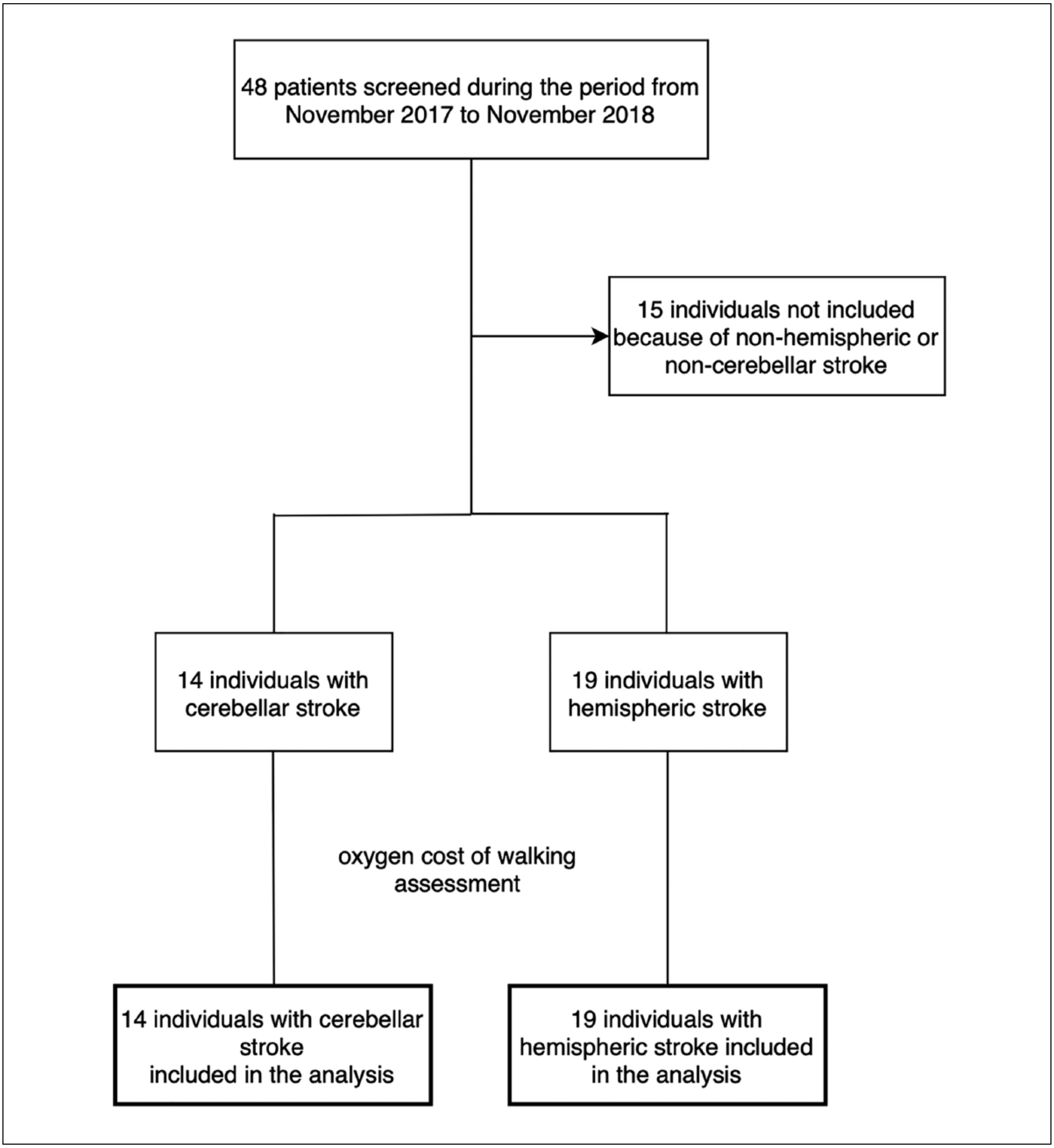

Figure 1. Flow chart.

exchange portable analyzer (Cortex Medical, Leipzig, Germany). The Metamax3B is a portable metabolic measurement system composed of a measurement module and a battery module. It measures gas volumes with a bidirectional digital turbine and analyzes the O_2 and CO_2 concentrations with an electrochemical cell and an infrared analyzer. The oxygen flow (VO_2) and carbon dioxide flow (VCO_2) were calculated using standard metabolic algorithms based on the Haldane transformation.[23] Respiratory volume data and respiratory gas concentrations were telemetrically transmitted in real time to a computer. The system was paired to the Metasoft 3 software, v3.7.0 SR2. The

Metamax3B was calibrated according to the manufacturer's recommendations prior to each test.[24]

Experimental Design

All participants performed the entire protocol under the same conditions. We restricted the consumption of food, nicotine, alcohol, and caffeine 3 hours before the experiment and other vigorous activities 12 hours before the experiment. The Metamax3B was first placed on the patient. The patient's gas exchanges at rest were recorded for 6 minutes while sitting in a chair. The patient was then asked to walk for 6 minutes in a 40-meter loop with no obstacle or U-turn. This specific duration was chosen due to the fact that about 4 minutes of exercise are required to achieve metabolic stability in individuals with chronic pathologies.[5] Several studies related to Cw in poststroke hemiparetic individuals have used a similar duration to obtain a stable metabolic state.[4,15]

Calculation of the Oxygen Cost of Walking

The VO_2 measurement was performed from the beginning to the end of the 6-minute walk. Cw was calculated from the patient's O_2 consumption measured at a stabilized metabolic rate, which is defined by a VO_2 variation lower than 2 $mL\,kg^{-1}\,min^{-1}$, as described in previous studies related to the oxygen cost of walking for poststroke individuals.[5] We calculated the Cw by dividing the VO_2 value at a stabilized metabolic rate per unit of time by the speed.[5] We chose to use the average walking speed over 6 minutes of walking, because this method demonstrates validity for the measurement of Cw.[13,25] On the other hand, this method of measuring the walking speed is equivalent to a measurement of 10 m,[22] and limits the practical constraints of measuring the walking speed in a steady-state condition, which would require further investigation (precise monitoring of the change in VO_2 during walking for the detection of the metabolic plateau and measurement of the instantaneous walking speed at the metabolic plateau). The speed value was calculated from the distance covered at the end of the 6 minutes of walking. The walking time was fixed and reported using a chronometer. The distance travelled was accurately measured using graduations on the ground (graduations every 5 meters). Thus, Cw was expressed in $mLO_2\,kg^{-1}\,m^{-1}$. We reported the respiratory exchange ratio (RER) values to verify that RER values were equivalent between patients. This parameter was measured using Metamax3b at the metabolic plateau during S.

Statistical Analysis

The objective of this study was to compare the Cw/S relationship between hemispheric stroke patients and cerebellar stroke patients. Since no studies had yet addressed this issue, we were unable to calculate the number of subjects necessary to observe a statistically significant difference.

We evaluated the normality of the distributions with the Shapiro-Wilk test. We compared normally distributed data by a fixed-factor ANOVA and nonnormally distributed data by a Mann-Whitney-type nonparametric test. Categorical data were analyzed using χ^2 tests. The correlation of speed and Cw was analyzed using the Spearman coefficient (r) and the coefficient of determination (R^2). The differences between the slopes and intercepts of the 2 logistic regressions were evaluated by means of a covariance analysis, as recommended by Geigy et al[26] and carried out in other work in the field.[15] This analysis made it possible to analyze the Cw of each group of subjects by walking speed rank. The difference in Cw at each speed rank was calculated for the 2 groups of patients using the Mann-Whitney test.

A correlation analysis was performed on the significantly different characteristics between the 2 groups. The objective of this analysis was to evaluate the relationship between Cw and the specific clinical characteristics of each of the 2 groups. The rule of thumb for interpreting the size of a correlation coefficient was the following: .90 to 1.00, very high correlation; .70 to .90, high correlation; .50 to .70, moderate correlation; .30 to .50, low correlation; .00 to .30, negligible correlation.[27] For all tests, the statistical significance threshold was $P < .05$. All statistical analyses were performed using the RealStats 2016 software (Real Statistics Using Excel 2012-2019, Charles Zaiontz).

Results

Thirty-three individuals were included (14 cerebellar stroke, 19 hemispheric stroke). No significant difference between the 2 groups was observed for all characteristics of the population except the Demeurisse upper limb score ($P = .008$), Demeurisse lower limb score ($P < .001$), Modified Ashworth Scale (MAS; $P = .008$), and ICARS ($P = .02$; Table 1). The RER for both groups of participants was similar ($RER_{\text{hemispheric stroke}} = 0.88 \pm 0.10$; $RER_{\text{cerebellar stroke}} = 0.90 \pm 0.11$; $P = .31$).

We identified a different Cw/S relationship between the hemispheric stroke group and the cerebellar stroke group. These relationships were expressed using the following logistic regression equations: $Cw = 0.1961.S^{-0.979}$ with $R^2 = 0.97$ for hemispheric stroke individuals; $Cw = 0.2667.S^{-0.716}$ with $R^2 = 0.83$ for cerebellar stroke individuals. The equations of the logistic regressions are shown in Figure 2. The difference in Cw at each walking speed level (Kruskal-Wallis test) revealed a significant difference between the 2 groups for individuals walking at a speed greater than 0.4 $m\,s^{-1}$ (Table 2; Figure 3). The severity of ataxia assessed by ICARS was highly correlated with Cw for the cerebellar

Table 1. Characteristics of the Participants[a].

	Hemispheric Stroke Individuals	Cerebellar Stroke Individuals	*P*
Age (years)	66.4 (13.2)	58.9 (12.8)	.15[b]
Gender (n male/n female)	13/6	13/1	.21
Body mass index ($m\,kg^{-2}$)	25.6 (3.8)	25.5 (5.6)	.90[b]
Time after stroke (days)	639 (1279)	61 (65)	.06
Demeurisse upper limb score (/100)	72.6 (25.5)	93.1 (11.5)	.008
Demeurisse lower limb score (/100)	76.5 (20.9)	97.1 (6.7)	<.001
MAS (/4)	0.9 (1.1)	0 (0.0)	.008
ICARS (/34)	7.7 (7.2)	16.0 (12.0)	.02
Speed ($m\,s^{-1}$)	0.69 (0.32)	0.77 (0.36)	.25[b]
FACm (/8)	5.3 (1.9)	5.3 (1.4)	.75
Barthel Index (/100)	82.1 (15.7)	85.4 (13.9)	.27

Abbreviations: Demeurisse, Demeurisse Motor Index; MAS, Modified Ashworth Scale; ICARS, postural and walking sections of the International Cooperative Ataxia Rating Scale; FACm, Functional Ambulation Classification–Modified.
[a]Data are expressed as mean (standard deviation) median.
[b]Reported to fixed-factor ANOVA because the groups were independent and the variables were continuous, with normal distribution in the Shapiro-Wilk test.

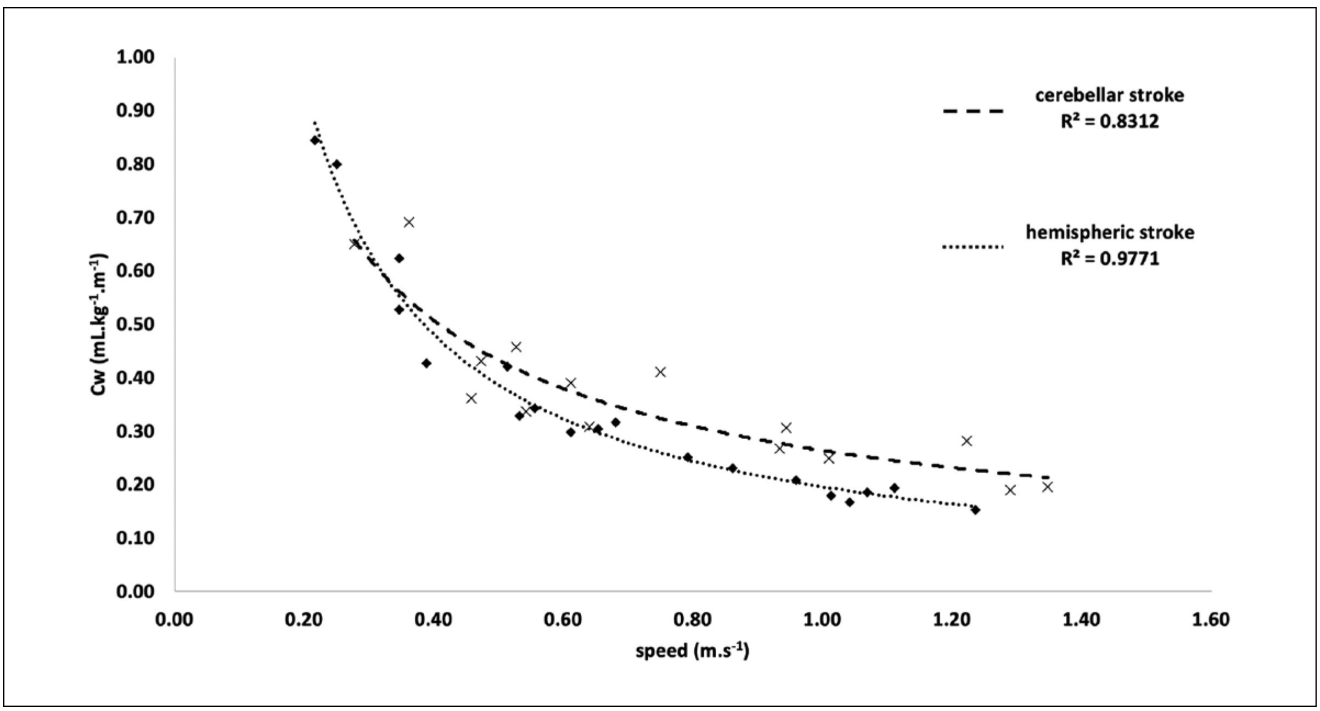

Figure 2. Logistic regression equations and coefficients of determination of Cw/S relationships in cerebellar stroke and hemispheric stroke individuals. × = Cw of cerebellar patient; ♦ = Cw of hemispheric patient.

stroke group ($r = 0.88$; $P < .001$). In the hemispheric stroke group, Cw was correlated with motor function in the lower limb ($r = -0.61$; $P = .003$), MAS ($r = 0.59$; $P = .007$), and ICARS ($r = 0.81$; $P < .001$; Table 3).

Discussion

This work revealed 2 different Cw/S relationships, depending on the location of the stroke ($Cw = 0.1961.S^{-0.979}$ for the hemispheric stroke group and $Cw = 0.2667.S^{-0.716}$ for the cerebellar stroke group). We showed that this difference between the 2 relationships was significant for S >0.4 $m\,s^{-1}$. Above this S we observed that ataxic individuals had a higher Cw (>30%) compared with hemiparetic individuals.

In the literature, other studies have shown differences in Cw/S relationships according to population type. For example, Zamparo et al designed a study in which healthy individuals (n = 17) were asked to adopt a walking speed

Table 2. Comparison of the 2 Logistic Regression Equations by Covariance Analysis[a].

Speed Rank (ms^{-1})			<0.2	0.2-0.39	0.4-0.59	0.6-0.79	0.8-1.0	>1.0
Cerebellar stroke patients	Cw ($mL\,kg^{-1}\,m^{-1}$)	Mean	0.67	0.40	0.40	0.29	0.25	0.22
		SD	0.03	0.06	0.01	0.03	0.03	0.05
Hemispheric stroke patients	Cw ($mL\,kg^{-1}\,m^{-1}$)	Mean	0.65	0.37	0.29	0.22	0.18	0.16
		SD	0.18	0.19	0.03	0.02	0.01	0.02
Cw cerebellar stroke versus Cw hemispheric stroke ($mL\,kg^{-1}\,m^{-1}$)		Mean difference (%)	4.08	8.99	36.27	30.63	36.83	39.87
		P	.85	.28	<.01	.04	.03	.01

[a]Cw ($mL\,kg^{-1}\,m^{-1}$) reported to the oxygen cost of walking; *P* values reported to the results of the covariance analysis made by the Kruskal-Wallis test.

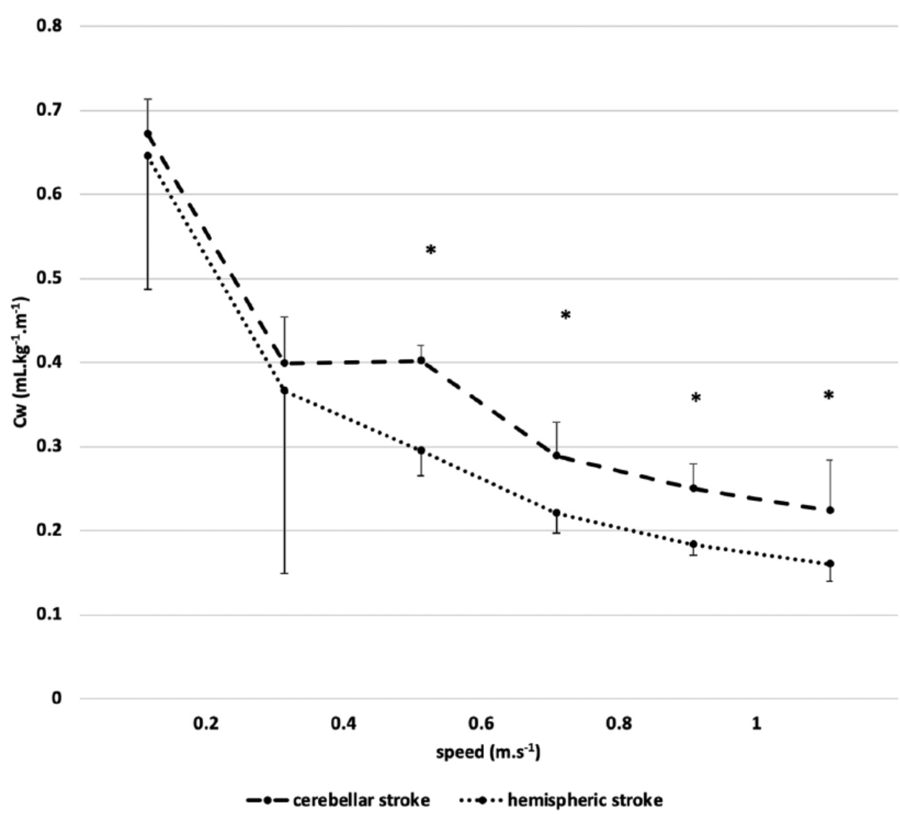

Figure 3. Comparison between the Cw/S relationship in cerebellar stroke and hemispheric stroke individuals.

equivalent to that of hemiparetic individuals (n = 20). It was found that the Cw/S relationship of healthy subjects had an identical plot shape to that of hemiparetic individuals, but with lower values. The Cw of healthy subjects was consistently about 10% to 30% lower than that of hemiparetic subjects, depending on the walking speed.[15] Bernardi et al have also reported differences in Cw/S relationships between groups of individuals with various impairments (ie, hemiparesis, paraparesis, quadriparesis, orthopedic disorders) and healthy subjects.[28] These results are also consistent with our previous work on Cw in patients with hemispheric stroke. Indeed, the comparison of the regression equation in the work of Compagnat et al[13] obtained from hemispheric stroke patients with that of the present study highlighted a very strong similarity, with an R^2 at 0.97 (Supplemental Figure S1). This reinforces the fact that most walking hemispheric stroke individuals have this relationship, regardless of their level of impairment.

The increase in Cw observed in patients could be linked to muscle coactivation. Muscle coactivation is the simultaneous activity of agonist and antagonist muscles crossing the same joint.[29] Muscle coactivation is an important

Table 3. Correlation Analysis Between Clinical Characteristics and Oxygen Cost of Walking in Hemispheric and Cerebellar Stroke Individuals.

		Age	BMI	Time Since Stroke	Demeurisse Upper Limb Score	Demeurisse Lower Limb Score	Ashworth Scale	ICARS	Speed	FACm	Barthel Index
Hemispheric stroke	*r*	0.12	0.14	0.25	−0.52	−0.61	0.59	0.81	−0.89	−0.68	−0.62
	P	.35	.73	.34	.14	<.01	<.01	<.01	<.01	<.01	<.01
Cerebellar stroke	*r*	0.57	0.06	−0.06	0.15	−0.02	0	0.88	−0.85	−0.61	−0.36
	P	<.01	.63	.78	.76	.69	N/A	<.01	<.01	<.01	.04

Abbreviations: *r*, Spearman coefficient between clinical variables and oxygen cost of walking; BMI, body mass index; ICARS, postural and walking sections of the International Cooperative Ataxia Rating Scale; FACm, Functional Ambulation Classification–Modified; N/A, not applicable.

component of motor control and joint stability,[30] but excessive coactivation can induce an increase in Cw.[31] Indeed, as any muscular activity leads to oxygen consumption,[23] the abnormal activity of the antagonist muscle leads to an increase in oxygen consumption. In addition, the agonist muscle must engage additional force to overcome the abnormal activity of the antagonist muscle.[32] Abnormal muscle coactivation is common after a hemispheric stroke.[33-35] Detrembleur et al reported that the increase in coactivation was estimated at 1.5 to 6 times longer than normal during all gait cycles in 9 hemiparetic individuals.[33] In addition, in our study, Cw was correlated with spasticity ($r = 0.59$; $P = .007$) in the hemispheric stroke group (Table 3). Further work would be necessary to evaluate the association between muscle coactivation and stroke patients' walking and Cw.

The authors are aware of no published research on muscle coactivation in individuals with post–cerebellar stroke sequelae. Muscle coactivation may be involved in a Cw increase for several different reasons in individuals with cerebellar stroke. The typical abnormal movements[36] generate their own oxygen consumption in addition to the usual muscular activity. Balance disorders[37] reinforce postural control strategies, which imply an increase in muscle recruitment and therefore oxygen consumption. Finally, a dyssynergia between agonist/antagonist muscles[36] can induce a loss of movement efficiency. To this end, we report a strong correlation between Cw and ataxia (ICARS) in the cerebellar stroke group ($r = 0.88$; $P < .001$). This phenomenon has been observed in multiple sclerosis individuals[38] and hemispheric stroke individuals[39] with balance disorders. It is therefore likely that strategies to compensate for balance disorders in individuals overexpress muscle coactivation, inducing a high Cw. It can be assumed that given the absence of a strength deficit, it is possible that muscle recruitment is greater in post–cerebellar stroke than in hemiparetic individuals, which could partly explain the difference between the 2 groups of individuals. However, further work in cerebellar stroke populations seems necessary to precisely determine the mechanisms that induce an increase in Cw.

The rank analysis shows a significant difference at a walking speed above 0.4 $m s^{-1}$ (Table 2). Below this threshold, the Cw of these individuals are not found to be different between the 2 types of stroke. We believe that this result is explained by the high variability of Cw for very low walking speeds. This variability can be explained in part by the low number of patients. However, other explanations remain. For example, some authors report that below a walking speed of 0.33 $m s^{-1}$, the locomotion of stroke individuals does not correspond to the usual properties of human walking, with a break in the linearity between spatial time parameters and walking speed.[40,41] For these slow speeds, the movement of stroke individuals would correspond more to "trampling" in individuals whose priority is to maintain their standing balance rather than their movement. It is therefore possible that these strategies for maintaining standing balance are not different between the 2 types of stroke, but scientific evidence is lacking to confirm this hypothesis. In future studies, it may be relevant to exclude individuals with a walking speed of less than 0.33 $m s^{-1}$ to homogenize the Cw analysis.

In this study we showed that Cw was significantly associated with several population characteristics (Table 3). This is particularly the case with scores assessing motor function, spasticity, and balance disorders. It is in line with the literature on motor function,[42,43] spasticity,[10,44] and balance.[45]

Among the study results, we also report that Cw was significantly correlated with age, especially in individuals with cerebellar stroke. The influence of age on Cw is also described in the literature.[46,47] Surprisingly, this relationship was not found in hemispheric stroke individuals, which may be due to our sample size: a larger cohort might reveal a significant correlation. Additionally, the poststroke times in the hemispheric stroke group were longer than in the cerebellar stroke group (639 vs 61 days), even if we did not find a significant difference in the statistical test. To explain these results, we analyzed the characteristics of the patients and found that 5 patients had a long poststroke time (>800 days), including one who had a poststroke time of 4700 days. This fact could explain the higher mean and standard deviation for the hemispheric stroke patient group. If hemispheric stroke individuals with a long stroke time were excluded, the Cw/S relationship would not be significantly different from the initial logistic regression equation: initial logistic regression equation: Cw = $0.1961.S^{-0.979}$; logistic regression equation (5 subjects with long poststroke time excluded) = $0.1946.S^{-0.974}$; $P = .96$. This is consistent with our previous work.[13]

It should also be noted that individuals in this study were overweight in both the hemispheric stroke group (body mass index [BMI] = 25.6 ± 3.8 kg m^{-2}) and the cerebellar stroke group (BMI = 25.5 ± 5.6 kg m^{-2}). A high BMI is reported as an increased Cw factor.[48] This characteristic is important and will require precaution when the Cw of the individuals in our study is compared with that of other individuals. It will be necessary to ensure that the BMI between individuals is comparable.

Practical Implications

The relationship between Cw/S highlights the differences between the Cw of ataxic individuals and hemiparetic individuals. Highlighting these differences has an impact on rehabilitation, because if the Cw of ataxic individuals is so large, this implies that interventions must absolutely focus on the individual's cardiorespiratory capacity. This seems fundamental to us, because such a high Cw in ataxic people certainly induces fatigue and a significant limitation of activity. Thus, an increase in the individual's cardiorespiratory capacity will improve walking tolerance and make it possible to maintain walking activity more durably. It is also important to work on the gait pattern to improve walking performance and to try to reduce the oxygen cost of walking. The other implication of this work is on the adaptation of the individual's environment. The fact that an individual has a very high Cw may alert the practitioner to the risk of fatigue and limited mobility in society. Thus, it seems unlikely that an individual with a high Cw (>0.55 mL kg^{-1} m^{-1} threshold value as defined by Franceschini et al for impacting social participation) could achieve significant walking distances. As a result, the practitioner will certainly have to propose adaptations to the patient's environment for limiting the patient's mobility distances, in order to limit as much as possible the impact on their independence and social participation.

Study Limitations

Our study was limited by the small number of participants, especially the low incidence of cerebellar stroke, which accounts for 6% of strokes.[49] The Cw/S relationship established for cerebellar individuals needs to be refined on a larger and more heterogeneous population of individuals in terms of age and impairments in order to be confirmed. Another limitation concerns the validation of the regression equation of the Cw/S relationship, since it has not been controlled on a new population and we have not assessed intra- and interreliability. These validity parameters will have to be evaluated by other studies, as has been done for hemispheric stroke individuals. Finally, an important limitation to our work is that we do not yet know the minimal clinically important difference of oxygen cost. We highlight a strong difference in Cw of about 31% to 40% between ataxic and hemiparetic individuals. Further work will need to be done to identify the minimal clinically important difference of oxygen cost and whether these differences in Cw are clinically relevant.

Conclusions

The Cw/S relationship is related to the type of stroke. The Cw of individuals with cerebellar stroke tended to be very high and was strongly correlated with ataxia. The results of this study seem to demonstrate a link between the type of stroke and Cw, which allows for the definition of individualized recommendations for physical activity based on an objective metabolic parameter. The impact on community walking needs to be explored in stroke survivors with cerebellar stroke.

Acknowledgments

We thank all our patients for volunteering to participate in this research. We thank our partners Autonom'Lab and European Network of Living Labs (ENoLL) and the region of Nouvelle-Aquitaine for their support throughout our work.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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