Original Article

JER

https://doi.org/10.12965/jer.2448128.064

Journal of Exercise Rehabilitation 2024;20(2):65-75

Neuro-orthopaedic check-up and walking in people with multiple sclerosis: toward a more specific assessment to improve rehabilitation results

Yoshimasa Sagawa[1,2], Coline Guilhendou[2], Thierry Moulin[1], Antonio Vinicius Soares[1,2,3,*], Pierre Decavel[1]

[1]Integrative and Clinical Neurosciences, UMR 1322 INSERM, University of Franche-Comté, Besançon, France
[2]Laboratory of Clinical Functional Exploration of Movement, University Hospital of Besançon, Besançon, France
[3]University of Joinville Region, Joinville, Brazil

The rehabilitation process of people with multiple sclerosis (PwMS) is a challenge, and decision-making requires a thorough assessment to increase the chances of success in rehabilitation planning. The aim of this study was to investigate the importance of the neuro-orthopaedic check-Up (NOChU) for gait prognosis. Participated in the study 105 PwMS with different levels of impairment. The NOChU includes measurements of passive range of motion (ROM), muscle strength, and spasticity. Additionally, was carried out the spatial-temporal analysis of the walking, Timed Up and Go test, and 6-min walk test. ROM remained relatively preserved to perform daily life activities except for ankle dorsiflexion. Muscle strength was also relatively preserved. Spasticity affected especially the ankle muscles, clearly the sural triceps. Among the NOChU measurements the catch seemed to have the most impact on walking on its different phases and on other activities. Accurate NOChU measurements play a crucial role in clinical settings, guiding informed decisions in rehabilitation planning. Future research endeavours could focus on exploring the correlations between NOChU deficiencies and the decline in walking capabilities among PwMS, with the goal of proposing personalized treatment strategies that address their specific requirements.

Keywords: Multiple sclerosis, Walking, Range of motion, Muscle strength, Spasticity

INTRODUCTION

Multiple sclerosis (MS) is a chronic autoimmune inflammatory disease of the central nervous system characterized by a demyelination of the white matter with damage to the axons. It progresses in spurs and mostly affects young adults (i.e., aged between 20 and 40). As there is no causal treatment of MS, therapies used prevent or minimize symptoms. The MS symptoms (Jakimovski et al., 2024) differ according to individuals (Ghorbanpour et al., 2023), but the most common are muscle weakness, muscle hyperactivity or spasticity; sensory symptoms (paraesthesia); visual symptoms; sphincter, sexual, cognitive, and psychiatric disorders; severe fatigue; pain; and walking disorders (Ghorbanpour et al., 2023; Jakimovski et al., 2024). A thorough assessment of gait is essential, since among the symptoms mentioned above, people with MS (PwMS) report that walking is the most affected function and that it should be treated as a priority (Ghorbanpour et al., 2023). Commonly, walking disorders can be treated with physiotherapy (Etoom et al., 2018) or drug-based medication (Goodman et al., 2015). Although drugs have little role to play in this disability (Surya, 2015).

To determine the best treatment to improve PwMS's walking performance; several assessments are conducted to evaluate the level of walking impairment. The most common is the expanded disability status scale (EDSS) (Cohen et al., 2023; Naseri et al., 2021). The EDSS is rated from 0 to 10, and scores between 4 and 7.5 related exclusively to PwMS's walking distance and the needs of technical aids for walking (Meyer-Moock et al., 2014). To clas-

*Corresponding author: Antonio Vinicius Soares
https://orcid.org/0000-0001-6090-1423
Integrative and Clinical Neurosciences, UMR 1322 INSERM, University of Franche-Comté, Besançon, F-25000, France
Email: antonio.vinicius@univille.br
Received: March 5, 2024 / Revised: March 18, 2024 / Accepted: March 24, 2024

sify PwMS, EDSS does not provide additional information on walking pattern or the ability to perform other daily living activities which depend on walking capacity. Additional walking tests are frequently administered alongside EDSS to reinforce its assessment (Bethoux and Bennett, 2011; Skjerbæk et al., 2019).

Several studies have focused on quantified walking analyses of PwMS. In terms of spatial-temporal walking parameters, it is well documented that when compared with healthy controls, PwMS have reduced walking velocity, cadence, swing phase and stride lengths and an augmented double support phase (Comber et al., 2017; Kelleher et al., 2010; Severini et al., 2017). These variations reflect a deteriorated walking pattern which is caused by neuromuscular dysfunction. A reduction in hip, knee and ankle range of motion (ROM) has been observed during walking (Filli et al., 2018; Kelleher et al., 2010; Severini et al., 2017). These results suggest the importance of knowing upfront the state of PwMS' joint function: whether PwMS's have adequate ROM, strength, and absence of spasticity. These analytical assessments are often conducted by a physiotherapist when a neuro-orthopaedic check-up (NOChU) is performed (Decavel and Sagawa, 2019).

The limited research on NOChU for PwMS shows that loss in ROM, although not originally a primary problem, can become one, particularly due to spasticity and motor control disturbed (Benedetti et al., 1999; Haselkorn and Loomis, 2005; Hoang et al., 2014). Joint stiffening becomes a first body response to the problem of postural control in walking (Benedetti et al., 1999), as, although it limits velocity and stride length, it improves the patient's balance and stability. However, in the long term, there is a negative impact on the maintenance of the musculoskeletal system, leading to difficulty in people's daily living activities and independency (Hoang et al., 2014; McNicholas et al., 2018). Moreover, this phenomenon is observed even in PwMS at the early stages of the illness (Benedetti et al., 1999).

While walking appears to be assessed by different approaches (e.g., EDSS, quantified walking analysis), few studies have focused on the NOChU and even less on the simultaneous analyses of walking disorders and the NOChU for a same PwMS sample. Thus, the intention of study was therefore to determine the association of the potential deficits identified during the NOChU that comprise tests of ROM, strength, and spasticity on walking functions of PwMS. This study aims to provide a better understanding of the effect of joint and muscle deficits on walking, and them, contribute to decision-making in physiotherapy.

MATERIALS AND METHODS

A retrospective search in the laboratory database, including NOChU and walking assessments that were conducted for the period of 5 years. The study was approved by the ethics committee of the University Hospital of Besançon (No. 13/405) and the French Health Products Safety Agency (No. 2013-A002305-56). All patients in the study gave their written and informed consent.

Participants

All PwMS sent to the Laboratory of Clinical Functional Exploration of Movement by the departments of Physical Medicine and Rehabilitation and Neurology experienced discomfort at walking. For selecting the PwMS, the following inclusion criteria were used: (a) clinical diagnosis of MS according to the McDonald's criteria. In summary, the criteria are based on: a person who has experienced at least two clinical attacks, and has clear-cut evidence of damage in at least two distinct brain areas, can be definitively diagnosed with MS, as that individual fulfils requirements for both dissemination in space and time (McNicholas et al., 2018); (b) patients positioned within the range of 0.5 to 7.0 on the EDSS scale; (c) individuals with a complete NOChU and walking assessment on the same day; (d) it was the first evaluation in the laboratory. The patients excluded were: (a) those with epilepsy or a history of epilepsy; (b) who had a change in their immunotherapy over the previous 60 days; (c) who were prescribed antispastic therapy and fatigue-reducing treatments respectively over the past 30 days.

All patients were evaluated by a neurologist and a physiotherapist with extensive experience in the management of PwMS.

Evaluations

The assessments described below were detailed in a previous study (Decavel and Sagawa, 2019).

Characteristics of the participants

All participants were examined by an experienced neurologist to confirm whether they fit the criteria. The characteristics monitored included their EDSS score, type of MS, years of illness, age, gender, weight, height, body mass index (BMI).

Neuro-orthopaedic check-up

This check-up is divided into the measurements of passive ROM, muscle strength and spasticity. Each PwMS was evaluated by experienced and specifically trained physiotherapist.

Passive ROM in the lower limbs was assessed using a goniome-

 https://doi.org/10.12965/jer.2448128.064

ter. The observed value in degrees and the ratio (%) between the observed value and the normative value (Kapandji, 2011) were calculated for the following lower limbs joints movements, at the hip: flexion, extension adduction, abduction, medial and lateral rotation; at the knee: flexion, extension, medial and lateral rotation; at the ankle: inversion and eversion, plantar and dorsal ankle flexion (knee tensed and bent for the latter). Voluntary muscle strength was evaluated using the Medical Research Council (MRC) scale. The MRC scales the strength from 0 to 5 according to each muscle function (Bohannon, 2018). Voluntary muscle strength was evaluated for the following muscles at the hip: flexors, extensors, abductors, and adductors; at the knee: flexors and extensors, and at the ankle: dorsiflexors, plantar flexors, investors, and eversors. Muscle spasticity was assessed through involuntary muscle hyperactivity of the lower limbs with the modified Tardieu scale (Haugh et al., 2006). This scale rates spasticity from 0 to 4; The catch angle was observed based on the last three ratings, as spasticity occurs at a specific angle (Haugh et al., 2006). Muscle spasticity was assessed for the following muscles at the hip: flexors, abductors, and adductors; at the knee: flexors and extensors; and at the ankle: triceps sural and soleus, anterior and posterior tibial, and fibular. The ROM and catch angle were expressed according to the anatomical configuration. For all joints tested, the flexion, abduction and eversion corresponded to a positive value and the extension, adduction and inversion to a negative value (Picelli et al., 2017). The NOChU was evaluated bilaterally. Since MS is a non-symmetrical disease, and each hemibody was considered in the observation (Filli et al., 2018).

Walking analysis

The spatial-temporal analysis of the walking was carried out in a dedicated room at 23°C and using a 6.10 m instrumented GAITRite (CIR Systems Inc., Clifton, NJ, USA). The same instructions were given to each patient. They were asked to walk 25 feet (7.62 m) and the mat was placed at mid-walkway. To avoid the acceleration and deceleration phases, PwMS were asked to start and stop walking 2 m before and after the 25 feet walkway, materialised by two floor lines perpendicular to the walkway. Three walking conditions were evaluated (Decavel and Sagawa, 2019): comfortable walking speed (CWS), fast walk speed (FWS) and CWS with a dual task (WSDT). The dual task consisted of walking and performing subtractions by series of seven most accurately. The number seven is described as not implying the walking rhythm (Conklyn et al., 2010). For each condition a minimum of 10 gait cycles were recorded (König et al., 2014). The walking variables selected for further analysis were walking velocity (m/sec); cadence (steps/min); stride length (m); difference in length between left and right step (m); support base (m); time difference between the left and right stance phase (% of the gait cycle) and double support time (% of the gait cycle). A Timed Up and Go (TUG) test was then conducted with a 0.47-m-high chair with armrests and a backrest (Nordin et al., 2008). PwMS had to get up from the chair, walk 3 m, round a cone and return to the chair walking as fast as possible. The TUG was performed twice. If the difference between the two tests was above 10%, a third test was conducted. The value used is the mean of the two closest tests. Finally, PwMS were asked to complete a 6-min walk test (6MWT) as recommended by the American Thoracic Society (ATS Committee on Proficiency Standards for Clinical Pulmonary Function Laboratories, 2002; Bethoux and Bennett, 2011). Encouragement was given to the PwMS at every minute. Instructions were read to them before starting the test. They had to walk on a 24-m circuit and walk the longest possible distance for 6 min. They could rest or use a technical walking aid if necessary. The tests were performed in the same order as they were described above.

Analysis

Descriptive statistical analyses were conducted using the Statistica software (StatSoft Inc., Tulsa, OK, USA). Depending on the nature of the data, they were presented in terms of mean (standard deviation, SD), median (interquartile range, IQR), and frequency distribution. The EDSS was used for subgroup analysis to characterize three levels of walking impairment severity. The light group who scored between 0 and 3.5 were PwMS without impaired ambulatory capacity. The moderate group who scored between 4 and 4.5 were PwMS whose walking was affected but who were autonomous. Finally, the high group who scored more or equal to 5 were PwMS who had lost their autonomy, were unable to perform daily tasks and using an aid to walk.

RESULTS

The total number of patients evaluated over a 5-year period in the laboratory was 212. However, 107 patients were excluded from the study due to lack of data, whether regarding NOChU and/or walking assessment. Since these data must be collected at the same time. Therefore, Table 1 shows the characteristics of 105 PwMS who met all inclusion/exclusion criteria. Sixteen patients were included in the light group, 49 in the moderate group, and 40 in the high group. Their mean ± SD age, height, weight, and BMI amounted to 51±12 years of age, 1.67±0.10 m, 75±15 kg, and 27±5 kg/m^2 (i.e., overweight according to the World Health Organization classification), respectively. The median (IQR) EDSS level was 4.5 (6–4).

ROM

When considering all hip movements tested (i.e., flexion, extension...), PwMS showed on mean range of 90% of the normal (%/norm). The most important limitation being at extension: 70%/norm. ROM decreased in all movements as the EDSS classes changed, except for the medial rotation. In knee flexion, PwMS had a mean amplitude of 87%/norm. For extension, the PwMS had a mean amplitude of 37%/norm. The values remained relatively stable according to the EDSS classes; the largest variation between classes being 5% points. For ankle dorsiflexion at knee flexed at 90°, PwMS had a mean amplitude of 52%/norm, while in a straight knee position the value equated only 35%/norm. For ankle plantiflexion, patients had a mean amplitude of 107%/norm. Ankle dorsiflexion at knee flexed at 90° decreased only in the high group while dorsiflexion when the knee was straight decreases progressively among EDSS classes. Plantiflexion did not change among EDSS classes. All details about ROM are showed in Table 2.

Table 1. People with multiple sclerosis characteristics

Characteristic	All (n=105)	Group		
		Light (n=16)	Moderate (n=49)	High (n=40)
Age (yr)	50.99±11.70	47.44±11.43	48.80±9.49	55.00±13.11
Height (cm)	167.47±9.51	167.28±11.56	169.51±9.32	165.11±8.36
Weight (kg)	75.42±15.22	71.96±11.51	77.03±16.42	74.85±14.89
BMI (kg/m^2)	26.80±4.82	25.75±3.66	26.77±5.16	27.25±4.77
EDSS	4.5 (6–4)	2.75 (3.5–2.5)	4 (4.5–4)	6 (6.5–5.5)
	n=65	n=0	n=29	n=36
Illness duration (yr)	14.32±9.90		11.48±8.70	16.61±10.26
	n=63	n=0	n=28	n=35
Type of MS				
SP:PP:RR	30:20:13		10:8:10	20:12:3

Values are presented as mean±standard deviation or median (interquartile range).
BMI, body mass index; EDSS, expanded disability status scale; SP, secondarily progressive; PP, primarily progressive; RR, relapsing-remitting.

Muscular strength

Table 3 shows the percentage of PwMS whose muscle strength was less than or equal to 3 according to the MRC scale (i.e., active movement against gravity in all the joint amplitude). Supplementary Table 1 shows PwMS frequency according to all the modalities of the MRC scale (i.e., from 0 to 5). In hip flexion, 28% of PwMS had strength less or equal to 3. The values for hip extension, abduction and adduction remained relatively close between them

Table 2. Passive range of motion

Level	All (n=105)		Group					
			Light (n=16)		Moderate (n=49)		High (n=40)	
	Angle (°)	(%/norm)	Angle (°)	(%/norm)	Angle (°)	(%/norm)	Angle (°)	(%/norm)
Hip								
Flexion	125.62±13.49	86.63±9.30	134.22±10.17	92.56±7.01	126.43±12.41	87.19±8.56	121.19±14.17	83.58±9.77
Extension	20.88±9.23	69.61±30.76	22.34±7.51	74.48±25.04	21.33±9.75	71.09±32.51	19.66±9.15	65.54±30.51
Abduction Kn St	47.57±13.07	105.71±29.05	53.13±13.60	118.06±30.23	48.21±11.95	107.14±26.57	44.56±13.48	99.03±29.96
Adduction	24.20±6.51	80.66±21.71	28.59±7.54	95.31±25.13	24.13±6.34	80.44±21.14	22.43±5.38	74.78±17.95
Medial rotation	37.64±12.05	125.48±40.16	36.56±10.51	121.87±35.02	35.36±11.43	117.86±38.08	40.96±12.77	136.54±42.56
Lateral rotation	44.38±12.06	73.25±21.26	47.81±12.89	79.69±21.48	46.63±13.29	77.72±22.15	40.13±8.49	65.21±17.48
Knee								
Flexion	139.43±13.16	87.14±8.23	143.75±12.89	89.84±8.06	141.43±11.21	88.39±7.01	135.19±14.44	84.49±9.03
Extension	3.71±4.44	37.08±44.40	3.59±4.79	35.94±47.92	3.52±3.88	35.20±38.80	3.99±4.96	39.87±49.60
Popliteal angle	29.21±15.96	16.33±9.27	22.97±10.76	12.76±5.98	31.17±16.35	17.32±9.09	29.30±16.75	16.56±10.28
Ankle								
Dorsal flexion Kn St	10.50±10.92	35.01±36.41	16.09±8.49	53.65±28.31	11.73±10.33	39.12±34.44	6.71±11.29	22.36±37.64
Dorsal flexion Kn Fl	20.77±13.47	51.91±33.67	23.44±10.35	58.59±25.88	23.32±12.50	58.29±31.24	16.52±14.75	41.30±36.87
Plantar flexion	53.65±13.04	107.31±26.09	53.91±13.66	107.81±27.33	53.93±13.15	107.86±26.29	53.21±12.82	106.41±25.63

Values are presented as mean±standard deviation.
%/norm, % of the normal; Kn St, knee straight; Kn Fl, knee flexed.

https://doi.org/10.12965/jer.2448128.064

with a mean of 15% of PwMS having strength less or equal to 3. In knee flexion, 36% of PwMS had strength less than or equal to 3, while for the knee extensors only 16% had a strength less or equal to 3. At the ankle, 18% of PwMS had strength less than or equal to 3 for all the muscles evaluated; in decreasing order this represented 21% for the anterior tibial, 19% for the fibular, 16% for the posterior tibial and 14% for the sural triceps. For all muscle groups, the frequency of PwMS with strength less than or equal to 3 increased with the EDSS classes. In contrast, this increase was more evident between the light to moderate than between the moderate to high groups.

Spasticity

Table 4 shows the percentage of PwMS with spasticity greater than or equal to 2 according to the Tardieu scale (i.e., at least one sharp jump interrupting the passive movement followed by a relaxation). Supplementary Table 2 shows PwMS classified according to all the modalities of this scale (i.e., from 0 to 4). At hip and

Table 3. The percentage of people with multiple sclerosis whose muscle strength was less than or equal to 3 according to the Medical Research Council scale

Level	All (n=105)	Group		
		Light (n=16)	Moderate (n=49)	High (n=40)
Hip				
Flexion	28	6	31	36
Extension	13	3	17	14
Abduction	17	6	17	20
Adduction	14	9	14	10
Knee				
Flexion	36	9	36	44
Extension	16	9	17	18
Ankle				
Triceps sural	14	0	13	23
Anterior tibial	21	0	14	35
Posterior tibial	16	3	17	23
Fibulars	19	3	22	25

Table 4. The percentage of people with multiple sclerosis with spasticity greater than or equal to 2 according to the Tardieu scale

Level	All (n=105)	Group		
		Light (n=16)	Moderate (n=49)	High (n=40)
Hip				
Flexors	4	0	5	4
Abductors	5	0	7	5
Adductors	9	0	9	13
Knee				
Flexors	15	13	16	16
Extensors	10	6	13	6
Ankle				
Triceps sural	52	63	59	44
Soleus	62	66	67	55
Anterior tibial	0	0	0	1
Posterior tibial	34	6	34	41
Fibulars	1	3	2	0

Table 5. Spasticity catch angle

Level	All		Group					
			Light		Moderate		High	
	No.	Angle (°)	No.	Angle (°)	No.	Angle (°)	No.	Angle (°)
Hip								
Flexors	8	27±25	0	NA	5	18±20	3	42±30
Abductors	11	17±6	0	NA	7	17±8	4	18±5
Adductors	19	27±10	0	NA	9	25±6	10	29±12
Knee								
Flexors	33	85±25	4	65±6	16	90±20	13	86±31
Extensors	17	71±25	2	95±7	10	72±23	5	59±29
Ankle								
Triceps sural	112	-3±8	20	-1±5	58	-2±8	34	-7±9
Soleus	130	0±7	21	2±6	65	1±7	44	-1±7
Anterior tibial	1	-10	0	NA	0	NA	1	-10
Posterior tibial	71	2±7	5	-1±5	34	2±8	32	2±6
Fibulars	3	-7±6	1	-10	2	-5±7	0	NA

NA, only for ratings greater than or equal to 2 according to the Tardieu scale.

knee level, few PwMS had spasticity greater than or equal to 2; a mean of 6% for hip muscles and 13% for knee muscles. At the ankle, a mean of 58% of PwMS had a spasticity greater than or equal to 2 in the sural triceps and soleus muscle; 34% had the same level of spasticity in the posterior tibial; barely 1% in the fibular and 0% in the anterior tibial. Increased spasticity did not appear to be associated with the EDSS classes except at the posterior tibial. At hip, the greatest variation observed between the light and the moderate group was for the adductors (9% points). At knee level, the most important variation (7% points) between the light to moderate group was in the extensors and the same was observed between the moderate and high group. At ankle level, the greatest variation (28% points) observed between the light to the moderate group was in the posterior tibial.

Table 5 shows the catch angle, the joint angle of the spasticity onset. At hip level, the catch angle was present at 27° for flexors and adductors, and 17° for abductors. The catch angle did not affect the light group, since all PwMS in this group had spasticity less than or equal to 1. For the moderate to high group, the catch angle appeared earlier. The greatest variation (24°) being in the flexors. At knee level, the catch of the flexors was present at 95°, and 71° for the extensors. For the flexors, between the light and moderate group the catch angle appeared earlier, and between the moderate and high group it remained stable. For the extensors, the catch angle appeared earlier according to the EDSS classes. At ankle level, the catch angle for the sural triceps was -3° and 0° for

Table 6. Walking conditions

Walking condition	All (n=105)	Group		
		Light (n=16)	Moderate (n=49)	High (n=40)
Comfortable				
Speed gait (m/sec)	0.86±0.37	1.15±0.21	0.95±0.36	0.64±0.30
Cadence (pas/min)	93.39±23.05	109.73±10.03	98.26±21.94	80.90±22.06
Stride length (m)	1.07±0.29	1.26±0.20	1.13±0.27	0.91±0.27
Stance time (% GC)	67.27±6.05	63.85±1.99	66.27±5.40	70.21±6.71
Double support (% GC)	35.03±11.09	27.78±3.00	32.72±9.79	40.76±12.04
Base support (m)	0.12±0.04	0.11±0.03	0.12±0.04	0.12±0.05
Step length diff L-R (m)	0.00±0.05	-0.01±0.02	-0.01±0.04	0.00±0.07
Stance phase diff L-R (% GC)	1.44±5.09	-0.01±2.85	1.64±4.54	1.77±6.30
Double task				
Speed gait (m/sec)	0.71±0.33	0.99±0.24	0.80±0.32	0.53±0.27
Cadence (pas/min)	83.26±23.49	100.05±12.14	89.23±22.47	71.65±21.91
Stride length (m)	0.98±0.28	1.18±0.21	1.05±0.26	0.85±0.27
Stance time (% GC)	63.93±7.14	64.74±3.05	67.35±5.72	71.93±8.23
Double support (% GC)	38.39±12.95	29.75±3.03	34.97±11.08	44.76±13.90
Base support (m)	0.13±0.05	0.11±0.03	0.13±0.04	0.13±0.05
Step length diff L-R (m)	0.00±0.06	0.00±0.04	-0.01±0.04	0.00±0.08
Stance phase diff L-R (% GC)	1.83±5.40	0.65±5.35	1.35±4.03	2.72±6.64
Fast				
Speed gait (m/sec)	1.31±0.56	1.75±0.43	1.46±0.46	0.88±0.41
Cadence (pas/min)	117.53±28.17	146.50±13.48	124.32±22.63	98.08±26.63
Stride length (m)	1.28±0.36	1.60±0.30	1.38±0.30	1.04±0.32
Stance time (% GC)	64.05±5.94	59.71±3.01	62.65±4.12	67.67±6.80
Double support (% GC)	28.49±10.62	20.58±4.57	25.64±7.02	35.68±11.68
Base support (m)	0.12±0.04	0.11±0.02	0.13±0.04	0.13±0.05
Step length diff L-R (m)	0.00±0.06	0.01±0.05	-0.01±0.04	0.01±0.08
Stance phase diff L-R (% GC)	1.27±5.04	-0.49±3.70	1.58±4.26	1.44±6.32
TUG (sec)	12.65±9.30	6.96±1.61	11.28±9.19	16.60±9.69
6MWT (m)	336.50±165.69	533.94±94.00	363.88±146.10	223.98±116.70

Values are presented as mean±standard deviation.
GC, gait cycle; diff, difference; L-R, left minus right; TUG, timed up and go; 6MWT, 6-min walk test.

https://doi.org/10.12965/jer.2448128.064

the soleus. For the anterior tibialis and fibular, this angle did not allow for interpretation given the small number of observations. For the posterior tibial the angle was 2°. Considering the EDSS classes, the catch angle appeared earlier between the moderate and light group for the sural triceps, while the value remained relatively stable for the posterior tibial and soleus.

Walking

Table 6 shows all the variables for all walking conditions as well as the TUG and 6MWT. Other than for the support base, the difference in stride length and the difference in the stance phase, which remained relatively stable between the different groups, a degradation of the walking in function of the EDSS classes was observed in all the other variables studied. At the TUG level, the mean value for all groups was 13 sec with a gradual increase according to the EDSS classes. At the 6MWT level, the mean value was 337 m with a progressive decrease according to the EDSS classes. Fig. 1 shows the physiological ROM required for walking and perform-

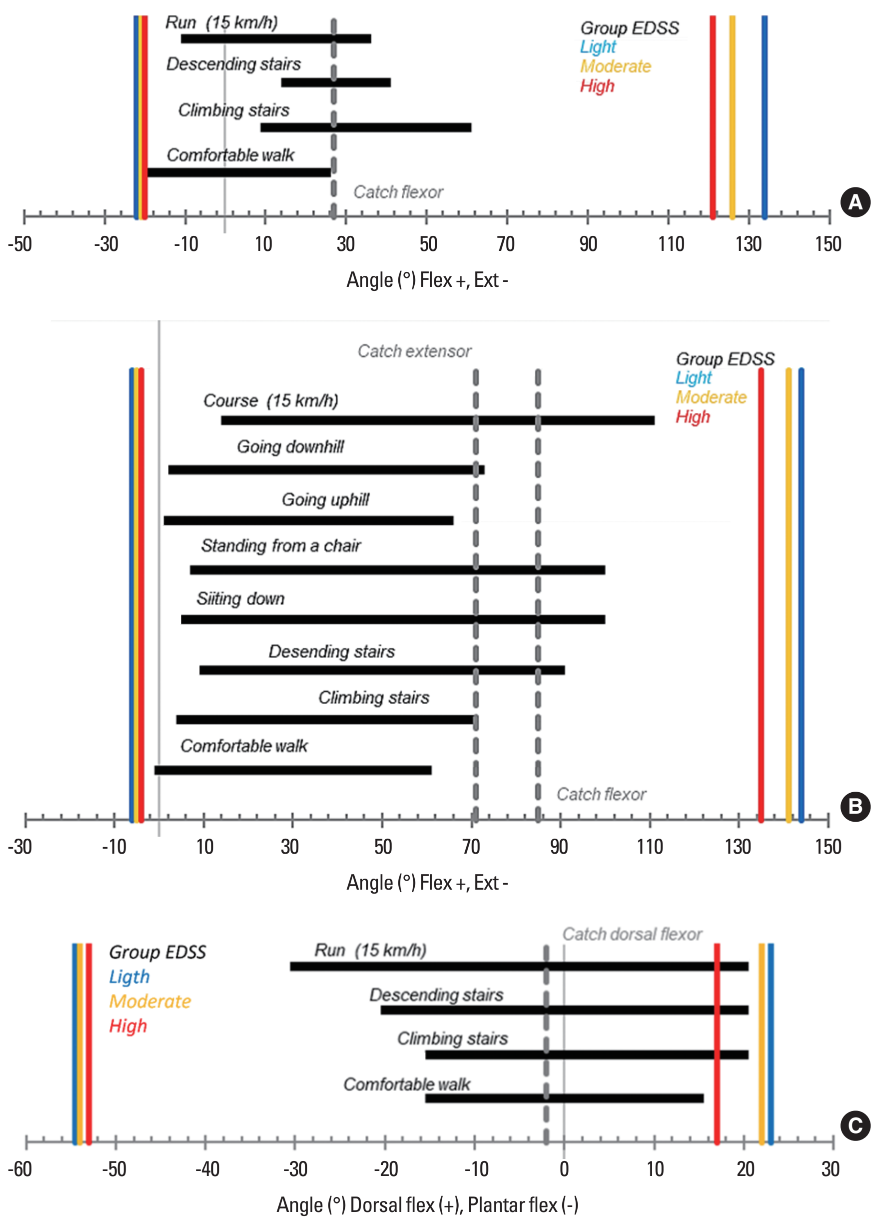

Fig. 1. Passive range of motion (A, hip; B, knee; C, ankle), catch angle, and angles required for different activities of daily life. For C, catch angle corresponds to the mean triceps sural. EDSS, expanded disability status scale; Flex, flexion; Ext, extension.

ing other daily life activities listed in different studies (Rowe et al., 2000), PwMS's ROMs and the mean catch angle according to EDSS groups. Few ROMs appeared to have an impact on the tasks listed except for hip extension and ankle dorsiflexion. On the other hand, the catch angle of all muscles is often in the middle of the joint amplitude necessary for these activities.

DISCUSSION

Although NOChU and walking evaluations are often practiced in PwMS clinical routine (Hoang et al., 2014; Mañago et al., 2018; Picelli et al., 2017), few studies are dedicated to NOChU and associate these two evaluations in a same population. This could bring new insights to determine the role of each joint and muscle during a routine physiotherapy assessment in a functional activity such as walking and then improve decision-making for therapeutic strategy. Initially, aspects related to NOChU (ROM, muscle strength, and spasticity) will be discussed, followed by walking assessment, and finally we will comment on the interactions between them. Regarding aspects relating to ROM, the hip mobility is relatively preserved except at extension. This deficit could be disturbing in daily living activities and leads to walking disturbances such as a diminished posterior step length. PwMS in the high group had a hip extension of 20°, which is considered as the minimum physiological extension necessary for walking at comfortable velocity (Hermez et al., 2023). This result suggests that more demanding walking conditions such as negotiating obstacles, increase walking speed or walking on an uneven ground could be challenging for PwMS. The knee extension was also limited with a mean value close to 0°, against a normal physiological value of a recurvatum of 10° (Kapandji, 2011). Despite this theoretical limitation, during walking and other daily living activities (Fig. 1B), the amplitude required does not exceed 0° suggesting that these limitations have a small impact on these activities.

Compared to all joints studied, the ankle was the most impaired, especially for the dorsiflexion. These results corroborate the only study that analysed a similar population sample (Hoang et al., 2014). The high group has a mean ROM of 17°. This value is very close to the walking limit at comfortable velocity, and remains below the value required to perform other activities. The physiological ROM for climbing and descending stairs is 20° (Hermez et al., 2023). This implies that PwMS must compensate with strategies such as hip-hinking, circumduction, vaulting or steppage to accomplish these daily tasks (Hermez et al., 2023). This limitation of the dorsiflexion is even more obvious when the knee is fully extended with a mean of 10°. These results suggest a hypo-extensibility of triceps sural (Krause et al., 2011). In an equivalent scenario, during the walking at the end of the double support phase, the knee is fully extended, and the ankle should be at 15°. In this walking phase reduced ankle dorsiflexion can have a negative impact on toe clearance preventing the passage for the next step, and consequently cause loss of balance, falls, or slower speed gait. Collectively for a physiotherapy strategy, it seems important to maintain ROM before it deteriorates throughout the MS course or to improve it if a ROM limitation already exists (Hoang et al., 2014). As it was previously observed and, in this study, in general, the above-mentioned loss of ROM is not a primary problem in PwMS, although it may eventually lead to joint retraction (Haselkorn and Loomis, 2005). Other factors that may affect joint retraction are strength and spasticity (Hoang et al., 2014).

Considering muscle strength, PwMSs were divided into two categories: <3 or ≥ 3 MRC scale. For walking, individuals need more than the equivalent to the force against gravity because of the extra load bearing joints (i.e., weight of the trunk (Sagawa et al., 2017), head, limbs...). The movement is no longer analytical and concentric as done during NOChU, but is a functional complex movement with concentric, isometric, and eccentric contractions (Fang et al., 2004; Hughes et al., 1996). Despite the different methodological approaches previous studies (Hoang et al., 2014; Mañago et al., 2018) showed a decline of strength in relation to the severity of MS. The loss of strength seems to be more important than those observed in our study (Hoang et al., 2014; Mañago et al., 2018). Although they used handheld dynamometry, not manual tests. Even if the weakness impairs walking (Hameau et al., 2017), our results suggest that muscle strength does not appear to be problematic for the majority of PwMS. In fact, for the hip and ankle, about one-fifth of PwMS had strength of 3 or less, and about one-quarter of PwMS had the same knee strength. The most deficient muscle group was the knee flexors; for about a third of PwMS. Another aspect of strength that was not measured in this study, is muscle fatigability. As walking is a cyclical movement, its observed degradation (Table 6) could be better associated with the capacity of a joint exercise repetition (Hameau et al., 2017). However, further studies are needed to confirm this hypothesis. In relation to spasticity, PwMS were divided in two groups according to the presence of a catch angle. A catch angle might induce discomfort while walking (Norbye et al., 2020). At hip level, there were few PwMS with spasticity greater than or equal to 2. However, for these patients the catch angle for hip flexors was at 27°. Indeed, this can have an impact on walking at the be-

 https://doi.org/10.12965/jer.2448128.064

ginning of the support phase when the lower limb is moving towards hip extension (Fig. 1) (Norbye et al., 2020). At knee level, there were few patients with spasticity greater than or equal to 2. However, for them, the catch angles for the flexors and extensors were 85° and 71°, respectively. During the walking, the catch angle of the extensors could cause discomfort at the beginning of the swing phase when they must flex the knee (Hermez et al., 2023). The catch angle of the flexors could also cause discomfort at the end of the swing phase when they must extend the knee and supported the foot on the ground to start a new gait cycle. However, during the stance phase, there is a minimal impact of these catches as the joint ROM required during this phase is lower (about 20°) than the observed catch angles (Hermez et al., 2023).

The most affected joint was the ankle, particularly the sural triceps and soleus (52% and 62% of PwMS had spasticity greater than or equal to 2, respectively). This result corroborates a previous study (Norbye et al., 2020). This spasticity is present during dorsiflexion. Moreover, the ankle was also concerned by the most affected passive ROM (Table 2). The catch angle for the posterior leg muscles is on mean -2°. This angle may affect daily living activities, starting with walking. This angle could interfere in the swing phase when the ankle must dorsiflex; this could cause falls as the toes drag. The catch angle could also interfere during the stance phase when the tibia must move forwards in relation to the foot (Hermez et al., 2023). A failure in this movement could have a repercussion on the knee by causing a dynamic recurvatum. Finally, it could also cause discomfort at the end of the swing phase when the ankle dorsiflexion contributes to start a new cycle, often by a heel strike (Hermez et al., 2023).

Several walking parameters (i.e., gait speed, cadence, stride length...), whatever the walking condition (i.e., CWS, FWS, WSDT), as well as the TUG and 6MWT deteriorated with the EDSS classes. These findings align with existing literature, which consistently confirms the significant impact of MS on walking ability (Hameau et al., 2017; Psarakis et al., 2017; Sosnoff et al., 2011). When the maximum passive amplitudes tested in the NOChU and independently of the EDSS are considered, they were generally larger than what is needed to perform daily living tasks (Fig. 1). These results suggest that the limitation of ROM does not appear to be the cause of the deficit in walking observed. Regarding the literature, when assessing the kinematics (i.e., joint movements) of walking in PwMS, the joint deflection in the lower limb is reduced, especially in knee flexion (Filli et al., 2018). Other factors appear to be responsible for this loss of joint movement, including the spasticity observed in this study; tiredness and muscle fatigability (de Haan et al., 2000); anarchic co-contraction of agonist and antagonist muscles or the individual's cardio-respiratory condition (Benedetti et al., 1999).

The use of NOChU and gait analysis are complementary and interactive information. Despite the willingness to conduct a comprehensive NOChU, further testing could be carried out or orientated towards those joints which seemed most impacted by the MS specially the ankle. In the absence of deficits observed in most of measurements in this study in terms of ROM and strength, other tests that consider other factors, such as muscle fatigability could also be performed in future NOChU investigations. We would advise to take a different approach to the NOChU at a different stage of MS and do this evaluation from the beginning of the disease.

From a clinical perspective, integrating the NOChU and referencing Fig. 1 in the patient's report could significantly enhance its utility in assessing the impact of potential deficits on daily living activities. In the multidisciplinary care approach for PwMS the incorporation of physiotherapy interventions is paramount (Feys et al., 2016; Khan and Amatya, 2017). It is crucial to establish a clear correlation between the localised impairments experienced by individuals and their consequent limitations in activities and participation restrictions. The potential of these investigations extends to laying the foundation for proposing personalized treatments aimed at addressing these specific impairments. This, in turn, holds the promise of enhancing the standard of care for individuals confronting MS. Ideally, we should have both information from NOChU and walking analysis to improve decision-making.

It is crucial to underscore certain limitations inherent in the study, such as testing for spasticity in more environmentally conditions, such as after testing walking or other activity of daily living. A second aspect would be in relation to using some measuring instrument to assess the sensation of fatigue. Since this is an important and recurring complaint among patients. Furthermore, investigate the impact of changes in NOChU and walking disorders on patient's perception of quality of life. Therefore, the entire rehabilitation process should focus on this aspect, since this is what really matters to the patient.

SUPPLEMENTARY MATERIALS

Supplementary Tables 1-2 can be found via https://doi.org/10.12965/jer.2448128.064.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

ACKNOWLEDGMENTS

The authors received no financial support for this article.

REFERENCES

ATS Committee on Proficiency Standards for Clinical Pulmonary Function Laboratories. ATS statement: guidelines for the six-minute walk test. Am J Respir Crit Care Med 2002;166:111-117.

Benedetti MG, Piperno R, Simoncini L, Bonato P, Tonini A, Giannini S. Gait abnormalities in minimally impaired multiple sclerosis patients. Mult Scler 1999;5:363-368.

Bethoux F, Bennett S. Evaluating walking in patients with multiple sclerosis. Int J MS Care 2011;13:4-14.

Bohannon RW. Reliability of manual muscle testing: a systematic review. Isokinet Exerc Sci 2018;26:245-352.

Cohen M, Mondot L, Landes-Chateau C, Lebrun-Frenay C. Towards a more precise rating of neurological disability in multiple sclerosis: a new automatic and linear quantification of limbs function. Mult Scler Relat Disord 2023;77:104904.

Comber L, Galvin R, Coote S. Gait deficits in people with multiple sclerosis: a systematic review and meta-analysis. Gait Posture 2017;51:25-35.

Conklyn D, Stough D, Novak E, Paczak S, Chemali K, Bethoux F. A home-based walking program using rhythmic auditory stimulation improves gait performance in patients with multiple sclerosis: a pilot study. Neurorehabil Neural Repair 2010;24:835-842.

De Haan A, de Ruiter CJ, van Der Woude LH, Jongen PJ. Contractile properties and fatigue of quadriceps muscles in multiple sclerosis. Muscle Nerve 2000;23:1534-1541.

Decavel P, Sagawa Y. Gait quantification in multiple sclerosis: a single-centre experience of systematic evaluation. Neurophysiol Clin 2019;49:165-171.

Etoom M, Khraiwesh Y, Lena F, Hawamdeh M, Hawamdeh Z, Centonze D, Foti C. Effectiveness of physiotherapy interventions on spasticity in people with multiple sclerosis: a systematic review and meta-analysis. Am J Phys Med Rehabil 2018;97:793-807.

Fang Y, Siemionow V, Sahgal V, Xiong F, Yue GH. Distinct brain activation patterns for human maximal voluntary eccentric and concentric muscle actions. Brain Res 2004;1023:200-212.

Feys P, Giovannoni G, Dijsselbloem N, Centonze D, Eelen P, Lykke Andersen S. The importance of a multi-disciplinary perspective and patient activation programmes in MS management. Mult Scler 2016;22(2 Suppl):34-46.

Filli L, Sutter T, Easthope CS, Killeen T, Meyer C, Reuter K, Lörincz L, Bolliger M, Weller M, Curt A, Straumann D, Linnebank M, Zörner B. Profiling walking dysfunction in multiple sclerosis: characterisation, classification, and progression over time. Sci Rep 2018;8:4984.

Ghorbanpour S, Rahimibarghani S, Rohani S, Rastkar M, Ghajarzadeh M. Fampridine for gait imbalance in patients with multiple sclerosis (MS): a systematic review and meta-analysis. Neurol Sci 2023;44:3059-3069.

Goodman AD, Bethoux F, Brown TR, Schapiro RT, Cohen R, Marinucci LN, Henney HR. Long-term safety and efficacy of dalfampridine for walking impairment in patients with multiple sclerosis: results of open-label extensions of two phase 3 clinical trials. Mult Scler 2015;21:1322-1331.

Hameau S, Zory R, Latrille C, Roche N, Bensmail D. Relationship between neuromuscular and perceived fatigue and locomotor performance in patients with multiple sclerosis. Eur J Phys Rehabil Med 2017;53:833-840.

Haselkorn JK, Loomis S. Multiple sclerosis and spasticity. Phys Med Rehabil Clin N Am 2005;16:467-481.

Haugh AB, Pandyan AD, Johnson GR. A systematic review of the Tardieu Scale for the measurement of spasticity. Disabil Rehabil 2006;28:899-907.

Hermez L, Halimi A, Houmani N, Garcia-Salicetti S, Galarraga O, Vigneron V. Clinical Gait analysis: characterizing normal gait and pathological deviations due to neurological diseases. Sensors (Basel) 2023;23:6566.

Hoang PD, Gandevia SC, Herbert RD. Prevalence of joint contractures and muscle weakness in people with multiple sclerosis. Disabil Rehabil 2014;36:1588-1593.

Hughes MA, Myers BS, Schenkman ML. The role of strength in rising from a chair in the functionally impaired elderly. J Biomech 1996;29:1509-1513.

Jakimovski D, Bittner S, Zivadinov R, Morrow SA, Benedict RH, Zipp F, Weinstock-Guttman B. Multiple sclerosis. Lancet 2024;403:183-202.

Kapandji AI. The physiology of the joint, the lower limb. 6 ed. vol. 2. Elsevier; 2011.

Kelleher KJ, Spence W, Solomonidis S, Apatsidis D. The characterisation of gait patterns of people with multiple sclerosis. Disabil Rehabil 2010;32:1242-1250.

Khan F, Amatya B. Rehabilitation in multiple sclerosis: a systematic review of systematic reviews. Arch Phys Med Rehabil 2017;98:353-367.

König N, Singh NB, von Beckerath J, Janke L, Taylor WR. Is gait variability reliable? An assessment of spatio-temporal parameters of gait variability during continuous overground walking. Gait Posture 2014;39:615-617.

Krause DA, Cloud BA, Forster LA, Schrank JA, Hollman JH. Measurement of ankle dorsiflexion: a comparison of active and passive techniques in multiple positions. J Sport Rehabil 2011;20:333-344.

Mañago MM, Hebert JR, Kittelson J, Schenkman M. Contributions of ankle, knee, hip, and trunk muscle function to gait performance in people with multiple sclerosis: a cross-sectional analysis. Phys Ther 2018;98:595-604.

McNicholas N, Hutchinson M, McGuigan C, Chataway J. 2017 McDonald diagnostic criteria: a review of the evidence. Mult Scler Relat Disord 2018;24:48-54.

Meyer-Moock S, Feng YS, Maeurer M, Dippel FW, Kohlmann T. Systematic literature review and validity evaluation of the expanded disability status scale (EDSS) and the multiple sclerosis functional composite (MSFC) in patients with multiple sclerosis. BMC Neurol 2014;14:58.

Naseri A, Nasiri E, Sahraian MA, Daneshvar S, Talebi M. Clinical features of late-onset multiple sclerosis: a systematic review and meta-analysis. Mult Scler Relat Disord 2021;50:102816.

Norbye AD, Midgard R, Thrane G. Spasticity, gait, and balance in patients with multiple sclerosis: a cross-sectional study. Physiother Res Int 2020;25:e1799.

Nordin E, Lindelöf N, Rosendahl E, Jensen J, Lundin-Olsson L. Prognostic validity of the timed up-and-go test, a modified get-up-and-go test, staff's global judgement and fall history in evaluating fall risk in residential care facilities. Age Ageing 2008;37:442-448.

Picelli A, Vallies G, Chemello E, Castellazzi P, Brugnera A, Gandolfi M, Baricich A, Cisari C, Santamato A, Saltuari L, Waldner A, Smania N. Is spasticity always the same? An observational study comparing the features of spastic equinus foot in patients with chronic stroke and multiple sclerosis. J Neurol Sci 2017;380:132-136.

Psarakis M, Greene D, Moresi M, Baker M, Stubbs P, Brodie M, Lord S, Hoang P. Impaired heel to toe progression during gait is related to reduced ankle range of motion in people with multiple sclerosis. Clin Biomech (Bristol, Avon) 2017;49:96-100.

Rowe PJ, Myles CM, Walker C, Nutton R. Knee joint kinematics in gait and other functional activities measured using flexible electrogoniometry: how much knee motion is sufficient for normal daily life? Gait Posture 2000;12:143-155.

Sagawa Y, Bonnefoy-Mazure A, Armand S, Lubbeke A, Hoffmeyer P, Suva D, Turcot K. Variable compensation during the sit-to-stand task among individuals with severe knee osteoarthritis. Ann Phys Rehabil Med 2017;60:312-318.

Severini G, Manca M, Ferraresi G, Caniatti LM, Cosma M, Baldasso F, Straudi S, Morelli M, Basaglia N. Evaluation of clinical gait analysis parameters in patients affected by multiple sclerosis: analysis of kinematics. Clin Biomech (Bristol, Avon) 2017;45:1-8.

Skjerbæk AG, Boesen F, Petersen T, Rasmussen PV, Stenager E, Nørgaard M, Feys P, Kjeldgaard-Jørgensen ML, Hvid LG, Dalgas U. Can we trust self-reported walking distance when determining EDSS scores in patients with multiple sclerosis? The danish MS hospitals rehabilitation study. Mult Scler 2019;25:1653-1660.

Sosnoff JJ, Weikert M, Dlugonski D, Smith DC, Motl RW. Quantifying gait impairment in multiple sclerosis using GAITRite technology. Gait Posture 2011;34:145-147.

Surya N. Rehabilitation of multiple sclerosis patients in India. Ann Indian Acad Neurol 2015;18(Suppl 1):S43-S47.