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TITLE PAGE

An investigation of commonly prescribed stretches of the ankle plantarflexors in people with Multiple Sclerosis

Running Title: Ankle Torques in Multiple Sclerosis

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KEYWORDS

Stretching, Multiple Sclerosis, Stiffness, Spasticity

ABSTRACT

Background

Stretches are often prescribed to manage increased limb stiffness in people with Multiple Sclerosis. This study determined the ankle plantarflexor torque magnitude that people with Multiple Sclerosis can apply during four commonly prescribed stretches and determined the relationship between the applied torque and functional ability.

Methods

People with Multiple Sclerosis (N=27) were compared to healthy control participants (n=15). Four stretches were investigated; stretching in step standing; using a step; pulling the ankle into dorsiflexion and standing in a frame. Joint position and forces were measured using 3D motion analysis and torque transducers. Baseline ankle strength and stiffness was measured using motor driven ankle perturbations.

Findings

People with Multiple Sclerosis (n=27) had higher stretch reflex amplitudes and lower strength compared to the control group (n=15). People with Multiple Sclerosis achieved less lengthening of the plantarflexor muscle-tendon complex when stretching but similar ankle torques compared to controls. While stretching people with Multiple Sclerosis showed greater muscle activation in the ankle plantarflexors. Stretches in weight bearing positions produced higher plantarflexor torques. People with Multiple Sclerosis with lower functional ability preferred the more supported stretches (ankle pull and standing frame).

Interpretation

Stretches in weight bearing positions achieve higher ankle torques but this is in part due to increased postural activity in people with Multiple Sclerosis. Functional ability may limit stretch effectiveness

Keywords Multiple Sclerosis, stretching, spasticity, hypertonia

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INTRODUCTION

Increased limb stiffness is seen in up to 80% of people with multiple sclerosis (MS) (1, 2) with the ankle plantarflexors being the most commonly affected muscle group(3). Increased limb stiffness is associated with reduced functional ability, quality of life and increased health and social care costs(4-7). It is caused by changes in passive stiffness and/or stretch reflex activation resulting in spasticity(8, 9). Stretching is commonly used as a treatment for symptomatic, increased limb stiffness(10, 11), based on the rationale that stretching promotes musculoskeletal adaptations that can prevent or correct increased passive stiffness and contracture (12) and reduces hypertonia by inhibiting the stretch reflex activity(13). However, a systematic review of stretch techniques aimed at reducing contracture in people with neurological conditions, highlighted the lack of evidence supporting stretching for the treatment of passive and stretch-reflex mediated stiffness(14). To date studies investigating stretching have varied widely in terms of the stretch parameters used such as the applied torque (the turning moment at a joint that results in a muscle stretch), the duration of stretch; the mode of delivery (eg via a motor, therapist or self-administered); the follow-up period (single session Vs longer term) and the muscle(s) targeted(14). These factors may influence the effectiveness of a stretch. Constant torque stretches, for example, are more effective in the short term reduction of limb stiffness than stretching in a constant position or cyclic stretching post stroke(15, 16). This study characterised the torques produced at the ankle during commonly applied manual stretches in people with MS and healthy participants. It further measured muscle activity during the stretch to assess whether the stretch is passive in nature.

Some commonly prescribed manual stretches require the person to be standing. In people with a neurological deficit achieving and maintaining these positions may be difficulty because of underlying neurological deficit such as muscle weakness and spasticity. We therefore also assessed the relationship between people's functional ability and how this impacted on the torques they could generate during a stretch, their preferred type of stretch and the duration they could maintain the stretch position. Understanding the torques generated during commonly prescribed stretches for the ankle plantarflexor, the degree of background muscle activity and the duration a stretch can be maintained could be important factors in determining the effectiveness of a stretch.

METHODS

Participants with MS (n = 27) were recruited through local MS neurology consultants. Participants were included if they scored between 4.5-7.0 on the Expanded Disability Status Scale (EDSS); were able to take a minimum of 10 steps with or without the use of a walking aid; transfer independently and passively achieve a neutral alignment of the foot between inversion and eversion with the foot in 10 degrees plantarflexion to allow reproducible positioning and stretching during motor-driven perturbations. People were excluded if they had additional neurological conditions not associated with MS, severe cognitive impairment such that they were unable to provide informed consent, or upper limb deficits that prevented them from consistently using the manual motor safety cut off switch used to measure baseline stiffness. People with MS were compared to 15 age, height and weight matched healthy controls that were recruited from local staff and acquaintances of people with MS. Written informed consent was obtained from all participants and the study was conducted with approval from the NHS Torbay and Devon Research Ethics Committee, UK.

Demographics and self-report measures of spasticity and function:

Participants completed self report questionnaires of symptom severity (EDSS, Expanded Disability status scale(15)), function (Barthel Index(16)), walking ability (12-item Multiple Sclerosis Walking Scale, MSWS-12(17)), spasticity (Multiple Sclerosis Spasticity Scale, MSSS-88(18)) and ankle plantarflexor hypertonia using the Ashworth scale(19). Demographic information (age, weight, gender) was also collected. Baseline ankle plantarflexor stiffness, stretch induced EMG activation and isometric strength were measured using a dynamometer as outlined in the supplementary material

Manually applied stretches:

Four stretches of the right plantarflexor muscles were assessed (figure 1); stretching in step standing (WALL); stretching off a step (STEP); pulling the ankle into dorsiflexion (PULL) and standing in an Oswestry Standing (FRAME). All stretches were first demonstrated using standardized instructions and each condition was practiced prior to data collection. Participants wore a safety harness attached to an overhead gantry during the stretches performed in standing and were not required to perform any stretch that could not be safely maintained. The stretch duration for all positions was 15 seconds and each stretch was repeated three times. A five minute rest was given between each group of stretches during which participants were asked to score the perceived strength and safety of the stretch immediately using a visual analogue scale (VAS) from one – five (strength: 1 = minimal stretch, 5= strong stretch; safety: 1= feel very unsafe,5 = feel very safe).

Following the four stretch conditions and a five minute rest period participants performed a constant sustained stretch in order to determine the length of time that they could hold a stretch (up to a cut off of 10 minutes) and the factors limiting the stretch. One stretch position out of the four stretching conditions was selected; this was based on the highest, safe (safety score ≥ 3) VAS score reported for perceived strength of stretch. Participants were asked to stretch in this position for as long as they felt comfortable while applying a force typical to the level they applied during their own home based stretching regimen. The duration of this stretch was recorded and the participants were asked to report why they had stopped stretching.

Measurement of ankle torque and gastrocnemius muscle-tendon length

The position of markers placed over bony landmarks on the lower leg was measured using motion analysis (Codamotion, Charnwood dynamics UK). Markers defined the longitudinal axis of the foot, shank and thigh and from this the ankle and knee angle in the sagittal plane was calculated. Two calibration trials with the ankle at 90^{o} and knee at 0^{o} were taken at the start to standardise the neutral ankle and knee position between participants.

For stretches in standing (WALL, STEP AND FRAME) the direction, magnitude and point of application of the applied force was measured via force plates (9286AA Kistler, Instruments Ltd, Hampshire, UK) that the participant stood on. For the STEP and WALL stretches only the leg of interest was in contact with the force plate. For the FRAME stretch both feet were in contact with the force plate and the load through each foot directly measured (FMAT, TEKSCAN, Biosense MedIcal UK); the applied torque was adjusted according to the percentage of load through the right leg. For the PULL stretch applied force was measured via a torque transducer in series with the strap, markers were positioned along the strap to define the direction of pull and point of application of the force. The net ankle torque produced during the stretches was estimated using inverse dynamics (21); it was normalised by the participants' body mass.

During the stretches the plantarflexor muscle-tendon length (PF length) was estimated using markers were placed on the muscle's distal (the tubercle of the calcaneus) and proximal attachment (posterior lateral femoral condyle) (20). PF length was normalised to body height

Muscle activity was recorded during the stretch from the tibialis anterior, medial gastrocnemius and soleus muscles via surface electromyography (2.5 cm inter-electrode distance, MT8, MIE, UK).

Motion analysis and force signals were sampled at 200Hz and muscle activity was sampled at 2000Hz and stored for off line analysis. EMG signals were subsequently filtered (30Hz low pass 2nd Order Butterworth filtered) and rectified. Mean rectified EMG activity during the 15s stretch was calculated and the grand average level of muscle activity from the 3 stretches undertaken per condition determined.

Analysis

Data was normally distributed as assessed using a Shapiro-Wilks test . Normalised mean ankle torque, PF length and EMG activity over the 5-15 s period of the stretch were compared between the MS and control groups using a between groups repeated measures ANOVA (SPSS 17.0, IBM). Factors were stretch condition (N=4, WALL, STEP, PULL, FRAME).A priori contrasts compared the difference between the WALL Vs STEP; STEP Vs PULL and PULL Vs FRAME conditions

Differences in muscle strength and stiffness between the groups were compared using an unpaired student t-test(see supplementary material). The relationship between functional ability and applied torque was determined using a Pearson's rank correlation .For all other statistical tests, the level of significance was set at $P<0.05$.

RESULTS

The study population comprised of 27 people with MS (age 54 ± 8.1yrs, height 168 ±10.5cm, weight 77 ± 19.3 Kg) and 15 healthy volunteers (age 53.4 ± 6.5 yrs, height 171 ±5.3cm, weight 81 ± 23 Kg). Fourteen people with MS had relapsing remitting MS; six primary and seven secondary progressive MS. Clinical descriptors are provided in table 1. The supplementary material provides a summary of the differences in strength, passive stiffness and stretch reflex activity.

Mean ankle torque during self-administered stretches

There was a significant difference between the conditions (CONDITION $F(3,120)= 33.9$ $P<0.001$, table 2); a priori contrasts revealed that the mean torque decreased significantly from STEP to PULL ($F(1,40)=100.8$ $P<0.001$, table 2) then increased significantly from PULL to FRAME ($F(1,40)=40.7$

$P<0.001$; Figure 2a, table 2). There was no significant GROUP X CONDITION interaction ($F(3,120)=0.6$ $P>0.05$, table 2) and no significant effect of group (GROUP $F(1,40)= 1.5$; $P>0.05$, table 2).

PF length during self-administered stretches

There was a significant effect of group with the controls achieving greater PF length while stretching compared to the people with MS(GROUP $F(1,40)= 7.2$ $P<0.05$, Figure 2b,table 2).There was no significant difference between the conditions (CONDITION $F(3,120)= 2.4$ $P>0.05$, Figure 2b,table 2). There was a significant GROUP X CONDITION interaction ($F(3,120)=9.1$ $P<0.005$,table 2). Contrasts revealed that there was a decrease in length from the STEP to PULL condition in the MS group whilst the muscle length stayed approximately the same in the controls ($F(1,40)=7.9 P<0.05$, Figure 2b, table 2). Muscle length increased in the MS group going from the PULL to the FRAME condition whilst it decreased in the control group ($F(1,40)=10.5$ $P<0.005$,table 2). In the FRAME condition muscle length was the same between the two groups in keeping with the fact that all participants stood in a standardised position with their foot and knee position constrained by the frame (Figure 2b,table 2).

Muscle activation during self-administered stretches

Tibialis anterior: There was a significant difference in tibialis anterior activation between the conditions (CONDITION $F(3,105)= 14.3$ $P<0.001$,table 2). There was higher muscle activation in the PULL condition compared to the STEP ($F(1,40)=13.6$; $P<0.001$,table 2) and FRAME conditions ($F(1,40)=20.9$; $P<0.001$,table 2,figure 3a). There was no significant GROUP X CONDITION interaction ($F(3,120)=0.38 P>0.05$,table 2) or group effect (GROUP $F(1,40)= 0.2$ $P>0.05$,table 2).

Gastrocnemius and soleus: Muscle activation in the two plantarflexor muscles during stretching showed identical trends and therefore only the gastrocnemius activity is reported. There was a significant difference in gastrocnemius activation between the conditions (CONDITION $F(3,120)= 6.7$ $P<0.005$,table 2) with activation being higher in the STEP compared to the WALL ($F(3,40)=21.7$

$P<0.001$,table 2) and PULL conditions ($F(3,40)=10.2$ $P<0.005$, table 2 Figure 3b). There was a significant GROUP X CONDITION interaction ($F(3,10)=3.0P<0.05$,table 2) with a larger increase in activation from the PULL to FRAME being seen in the control groups ($F(1,40)=3.9P<0.05$ Figure 3b). There was a trend towards a group difference (GROUP $F(1,40)= 3.7$ $P=0.057$, Figure 3b), EMG activity was higher in people with MS in the WALL, STEP and PULL conditions but similar to the controls in the FRAME condition

Relationship between ankle torque and functional ability

In people with MS there was no significant correlation between mean ankle torque and functional or walking ability as measured by the Barthel Index (Wall $R^2=0.16$ Step $R^2=0.002$ Pull $R^2=0.001$ OSF $R^2=0.07$ $P>0.05$) and MSWS12 (Wall $R^2=0.16$ Step $R^2=0.005$ Pull $R^2=0.02$ OSF $R^2=0.05$ $P>0.05$).

Subjective rating of stretches and duration of stretching

The WALL and the STEP stretch were rated by people with MS as producing the strongest stretches and had similar safety ratings (Figure 4). The WALL stretch was chosen by 61.5% of the people with MS as the stretch that gave them the strongest sensation of stretch, whilst 23.1% chose the STEP, 11.5% the FRAME and 3.9% chose the PULL. One person did not choose to perform the longer stretch due to fatigue. The people with MS who chose to subsequently stretch using the FRAME or PULL conditions were more disabled, with higher EDSS and lower Barthel index scores (n=4 Median (Interquartile range) EDSS =6.5 (1.13), Barthel = 75 (18.75)) compared to those that chose the WALL or STEP conditions (n=22, EDSS= 5.75, (1.5), Barthel =95 (15.0)) .

On average, people with MS were able to maintain a stretch for 148.4 s (+/-134.7s) with longer stretch durations being seen in the FRAME and PULL conditions (296s +/-419s) compared to the WALL and STEP conditions (118 +/-86s). In the most commonly chosen stretch, the WALL stretch, fatigue in the arms was given most frequently as the reason for cessation of the stretch (42.9% of cases) with other reasons being fatigue in the stretching leg (28.6%); general fatigue (26.4%) or discomfort in the neck region (7.1%).

DISCUSSION

The aim of this study was to enhance understanding of the amplitude of the torques that could be achieved using commonly prescribed manual stretches for the plantarflexor muscles and the relationship between the torques achieved and the presenting functional ability in people with MS.

The ankle plantarflexor torque produced while stretching significantly varied between the different stretching conditions, with both groups producing higher torques in the standing conditions (WALL and STEP). This is supported by the subjective ratings of people with MS, the majority of whom rated the standing stretches as those which were associated with a strong sensation of stretch. Higher ankle torques in the WALL and STEP stretch were probably due to the use of body weight to apply a constant torque. In both groups less ankle torque was produced when manually using the arms to stretch the ankle (PULL). For the people with MS this resulted in less PF length when compared to other stretches; this may reflect weakness of the upper limb muscles resulting in a reduced ability to generate sufficient force to stretch the plantarflexor muscles. Lower net ankle plantarflexor torque in the PULL condition may also reflect the observed increase in activation of the tibialis anterior muscle.

The controls achieved a significantly longer PF length when stretching compared to people with MS . Other methods such as combining ultrasound with 3D motion analysis would provide more accurate measures of PF muscle-tendon length and could provide a measure of the relative length of the muscle-tendon component. The applied ankle torque did not differ between the groups. A net plantarflexor ankle torque could be caused by forces associated with passively stretching the plantarflexors or actively contracting the plantarflexors; the inverse dynamics approach used in the current study to calculate the ankle torque is unable to distinguish between these possibilities. Further, the presence of co-contraction of the ankle plantar- and dorsiflexors could have reduced the net plantarflexor moment recorded during stretching. While stretching the gastrocnemius EMG was found to be higher in the people with MS in the WALL, STEP and PULL stretching conditions highlighting that the stretch and generation of ankle torque in people with MSwas not totally passive in nature. The increased muscle activation may reflect postural activity resulting from poor standing balance or a stretch evoked contraction of the muscle. This muscle activity may reduce the effectiveness of the stretch in people with MS.

No significant correlations were found between measures of functional ability suggesting that, in this sample of mild to moderately disabled people with MS (EDSS 4.5 – 7.0), functional capability did not significantly impact on the amount of torque that can be produced. When asked to choose a stretch that they perceived to be both “strong” and “safe” to implement, people with MS with lower functional ability tended to choose the FRAME and PULL conditions whilst those with higher functional ability tended to choose the WALL and STEP stretches. People choosing the FRAME and PULL conditions were able to hold the stretch for longer than the other conditions that required standing balance and antigravity activity. Thus, although the PULL and FRAME stretch elicit lower ankle torques when measured objectively the positions can be held for longer.

This study assessed people with MS with subjectively and objectively demonstrable hypertonia and spasticity (see supplementary material). It that commonly prescribed stretches for the ankle plantarflexor may vary in the effective stretching force, the degree of background muscle activity, subjective rating of safety and stretch effectiveness and the duration a stretch can be maintained.

Understanding these factors will help to inform future studies exploring the impact of stretch parameters such as applied torque and stretch duration on limb stiffness and contracture.

REFERENCES

1. Barnes MP, Kent RM, Semlyen JK, McMullen KM. Spasticity in Multiple Sclerosis. Neurorehabilitation and neural repair. 2003;17:66-70.

2. Rizzo MA, Hadjimichael OC, Preiningerova J, Vollmer TL. Prevalence and treatment of spasticity reported by multiple sclerosis patients. Multiple Sclerosis. 2004;10:589-95.

3. Hoang PD, Gandevia SC, Herbert RD. Prevalence of joint contractures and muscle weakness in people with multiple sclerosis. Disabil Rehabil. 2014;36(19):1588-93.

4. Hoang P, Saboisky J, Gandevia SC, Herbert RD. Passive mechanical properties of gastrocnemius in people with multiple sclerosis. Clin Biomech (Bristol, Avon). 2009;24(3):291-8

5. Arroyo R, Massana M, Vila C. Correlation between spasticity and quality of life in patients with multiple sclerosis: the CANDLE study. Int J Neurosci. 2013;123(12):850-8.

6. Svensson J, Borg S, Nilsson P. Costs and quality of life in multiple sclerosis patients with spasticity. Acta Neurol Scand. 2014;129(1):13-20.

7. Sosnoff JJ, Gappmaier E, Frame A, Motl RW. Influence of spasticity on mobility and balance in persons with multiple sclerosis. J Neurol Phys Ther. 2011;35(3):129-32.

8. Sinkjaer T, Toft E, Larsen K. Non-reflex and reflex mediated ankle joint stiffness in multiple sclerosis patients with spasticity. Muscle and Nerve. 1993;16:69-76.

9. Zhang LQ, Chen K, Kang SH, Sliwa JA, Cohen BA, Rymer WZ, et al. Characterizations of reflex and nonreflex changes in spastic multiple sclerosis. J Neurosci Methods. 2014;231:3-8.

10. Bhimani R, Anderson L. Clinical understanding of spasticity: implications for practice. Rehabilitation research and practice. 2014;2014:279175. Epub 2014/10/03.

11. Satkunam LE. Rehabilitation medicine: 3. Management of adult spasticity. CMAJ. 2003;169(11):1173-9.

12. Gorter JW, Becher J, Oosterom I, Pin T, Dyke P, Chan M, et al. 'To stretch or not to stretch in children with cerebral palsy'. Dev Med Child Neurol. 2007;49(10):797-800; author reply 799..

13. Maynard V, Bakheit A, Shaw S. Comparison of the impact of a single session of isokinetic or isotonic muscle. Clin Rehabil. 2005;19(2):146-54.

14. Katalinic OM, Harvey LA, Herbert RD. Effectiveness of stretch for the treatment and prevention of contractures in people with neurological conditions: a systematic review. Phys Ther. 2011;91(1):11-24.

15. Bowen J, Gibbons L, Gianas A, Kraft GH. Self-administered Expanded Disability Status Scale with functional system scores correlates well with a physician-administered test. Mult Scler. 2001;7(3):201-6.

16. Yeo D, Faleiro R, Lincoln N. Barthel ADL Index: a comparison of administration methods Clinical rehabilitation. 1995;9(1):34-9.

17. Hobart JC, Riazi A, Lamping DL, Fitzpatrick R, Thompson AJ. Measuring the impact of MS on walking ability: the 12-Item MS Walking Scale (MSWS-12). Neurology. 2003;14:31-6.

18. Hobart JC, Riazi A, Thompson AJ, Styles IM, Ingram W, Vickery PJ, et al. Getting the measure of spasticity in multiple sclerosis: the Multiple Sclerosis Spasticity Scale (MSSS-88). Brain. 2006;129:224-34.

19. Ashworth B. Preliminary trial of carisoprodol in multiple sclerosis The Practitioner. 1964;192:540-2

20. Jonhagen S, Halvorsen K, Beniot DL. Muscle activation and length changes during two lunge exercises: implications for rehabilitation. Scand J Med Sci Sports. 2009;19:561-8.

21. Happee R. Inverse dynamic optimization including muscular dynamics, a new simulation method applied to goal directed movements. J Biomech. 1994;27(7):953-60.