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ORIGINAL ARTICLE

Spasticity changes in SCI following a dynamic standing program using the Segway

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Study design: A pilot prospective pre- and post-intervention study.

Objectives: To determine whether a dynamic standing program using the Segway Personal Transporter results in any measurable physiological effects in individuals with spinal cord injury (SCI) using both qualitative and quantitative measures of spasticity, pain and fatigue.

Setting: International Collaboration of Repair Discoveries (ICORD) Research Centre, Vancouver, BC, Canada.

Methods: Eight individuals with SCI ASIA (American Spinal Injury Association) A–D, who could stand with or without the assistance of bracing or supports, participated in a 4-week dynamic standing program using a Segway (3 per week, 30-min sessions). The main outcome was spasticity as measured by the Modified Ashworth Scale (MAS). Secondary measures included the SCI-Spasticity Evaluation Tool, Pain Outcomes Questionnaire, and Fatigue Severity Scale.

Results: The dynamic standing sessions were associated with immediate improvements in spasticity (MAS) ($P<0.001$) and self-reported pain ($P<0.05$). Fatigue levels decreased, however this was not significant. There is little evidence to suggest that these beneficial outcomes may have lasting effects.

Conclusions: Dynamic standing on the Segway may be effective for short-term spasticity reduction and decreased pain and fatigue. Future work should examine a larger sample size and help to propose mechanisms for potential reductions in spasticity.

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Keywords: Segway; spasticity; spinal cord injury; pain; fatigue

INTRODUCTION

Up to 78% of people with spinal cord injury (SCI) suffer from spasticity,[1] which can inhibit movement and performance of activities of daily living (ADLs) and contribute to poor self-esteem, low body image, pain and fatigue.[2] Although spasticity has negative consequences for many individuals, we acknowledge that spasticity may have a beneficial effect that can improve weight-bearing and postural support.[3] It is reported that 48–94% of those with SCI who experience spasticity deal with significant neuropathic, musculoskeletal or visceral pain, as well as fatigue that interferes with ADLs.[4] Thus, spasticity, pain and fatigue are major barriers to the quality of life for those with SCI.

The Segway Personal Transporter (Segway Inc., Bedford, NH, USA) is a popular mobility device among able-bodied individuals. Previous research investigating whether the Segway could be used as a mobility device for people with disabilities was completed to determine what minimal functional ability was required to operate a Segway. Sawatzky, *et al.*[5,6] showed that very little strength, flexibility and coordination was needed to operate the Segway and that it provided a good alternative to existing equipment used by those with disabilities. Some individuals with SCI reported significant reductions in their spasticity during and after use of the Segway.

The purpose of this study was to determine whether reductions in spasticity, pain and fatigue can result from a dynamic standing program using the Segway, and whether these potential benefits have an immediate or a long term effect.

MATERIALS AND METHODS

Participants

We recruited nine individuals with SCI (ASIA A–D) aged ⩾19 years, who were at least 1 year post-injury and had the ability to stand with or without external support (for example, using long leg braces). Participants were required to have a history of both: (1) spasticity (Modified Ashworth Scale; MAS⩾1) in one or more muscle groups, and (2) chronic neuropathic pain for at least three months before the study. We excluded those with any history of a traumatic brain injury.

Clinical outcome measures

Our primary outcome was the MAS. This is the most widely accepted clinical, objective measure for limb spasticity.[7,8] MAS grades the resistance of a relaxed limb to rapid passive stretch in six stages. A rating of '0' relates to normal muscle tone and '4' signifies rigidity of the limb. Participants' muscle groups were assessed by one of two MAS-trained physicians, depending on their availability.

Self report measures

Secondary outcomes included three self-evaluation tools with validated psychometric properties used to assess spasticity, pain and fatigue. The Spinal Cord Injury Spasticity Evaluation Tool' (SCI-SET) is a 35-item, 7-day recall questionnaire that targets aspects of daily life relevant to the SCI population, which allowed respondents to rate the overall impact of their spasticity.[2] Responses in the SCI-SET are bidirectional and can range from −3 (extremely problematic) to +3 (extremely helpful), with the option of choosing '0' if spasticity had no effect on the activity/aspect of life in question. A positive total score would indicate that the individual perceived their spasticity as a

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benefit, whereas a negative total score suggested that it is a greater hindrance. An average score was calculated, excluding any non-applicable items.[2]

For evaluation of pain, the Pain Outcomes Questionnaire (POQ-VA) was used.[9] It is a primary pain outcome tool comprising 19 items examining pain history, average pain intensity, pain interference, emotional distress, pain-related fear, satisfaction with treatment and medication use. The numerical rating scale ranges from 0 (no pain interference) to 10 (significant pain interference). Positive and negative polarity of the scale is varied across the instrument to prevent systematic response bias. Although the POQ-VA has not been specifically validated for the SCI population, it has been shown to be reliable, valid and sensitive to changes associated with pain management among veteran patients.[10]

The Fatigue Severity Scale (FSS) comprises a unidimensional numerical rating scale containing nine items, which are rated with respect to the effects of fatigue on function. The outcome provides a broad picture of the global effects of fatigue and targets the impact of a specific activity on the symptoms of fatigue. Mean scores of $\geqslant 4$ are considered clinically fatigued. The measure has been shown to be valid and reliable for assessment with the SCI population.[11,12]

Protocol

Participants self-selected their top three muscle groups in which they experienced the greatest degree of spasticity. This included either upper or lower limb muscles. A baseline MAS was measured and recorded for these muscle groups. The examiner was blinded to these results at future visits. Participants completed the SCI-SET, POQ VA and FSS questionnaires before beginning the first Segway session.

Following the assessments, participants underwent a supervised 30 min training session, which included simple tasks like navigating around the indoor gymnasium, hallways and negotiating around obstacles with increasing levels of difficultly. Some training sessions were done outdoors to vary the experience. At completion of the Segway session, MAS was measured by the same physician. Subsequent Segway training sessions were completed three per week for 4 weeks, making a total of 12. Reassessment of *all* measures was repeated at the sixth session (Mid test) and twelfth session (Final test).

Data analysis

Owing to its preliminary nature and small sample size, the analysis was primarily descriptive, with means and s.e.m. reported. However, some comparative statistical analyses were completed. To obtain a single spasticity score for each person, the MAS scores of the three self-selected muscles groups were summed to get a Modified Ashworth Sum Score (MASSum) as described by Lechner *et al*.[13] The same day pre and post values were compared to determine whether the training had an immediate effect on MASSum scores using a Wilcoxon signed-rank test. To determine a longer-term effect, pre training MASSum scores for the initial, mid and final visits were compared using a Friedman analysis of variance (ANOVA). To assess the effect of training on self-reported spasticity, pain and fatigue, a 1×3 repeated measures ANOVA was used to compare initial, mid and final visits for the SCI-SET, POQ-VA, pain log and FSS data. SPSS v16.0 software was used IBM, Armonk, NY, USA. Significance was set *a priori* at $P<0.05$.

All participants gave written and verbal informed consent to participate. This study was conducted in accordance with the guidelines of all applicable institutional and governmental regulations concerning the ethical use of human volunteers during the course of this research.

RESULTS

Eight participants completed the program. One person dropped out because of personal reasons unrelated to study. Demographic information is shown in Table 1.

Spasticity

The dynamic standing program using the Segway showed immediate reduction in spasticity, which was evident in the entire pool of participants (Table 2). Individual muscle MAS scores decreased immediately following the intervention (pre- post-Segway intervention) in at least two of the three muscle groups for every subject except one (S5). Some scores improved by as much as three MAS grades for a given muscle after a single session. Two subjects (S1 and S2) showed improvements in MAS for each muscle in every session. MASSum showed a significant drop immediately from pre-training (5.6) to post-training (3.3) ($P<0.001$). Improvement over time was not statistically significant, however, scores decreased (6.2–5.1). The largest change occurred between the first visit and the mid visit (Figure 1). The MASSum did reduce for five of the eight participants from the first visit to the final visit. It did not change for two participants and increased during the study for one participant from 5.5 to 7 (Table 2).

Self-evaluations of spasticity using the SCI-SET improved from -0.91 (± 0.30) at initial visit, to -0.63 (± 0.24) for midway and again at the final visit to -0.57 (± 0.24), however these differences were not statistically significant (Figure 1).

Table 2 Sum spasticity MASS scores for the three visits

Subject no.	*Visit 1*	*Visit 2*	*Visit 3*
1	8	7	6
2	6	4.5	4.5
3	6	5	3.5
4	4.5	4.5	2
5	5.5	4.5	7
6	7	7	7
7	6.5	4	5
8	7	7	7

Abbreviation: MASS, Modified Ashworth Sum Score.

Table 1 Participant demographics

Sub	*Sex*	*Age*	*Injury level*	*ASIA*[a]	*Year(s) since injury*	*Daily meds*	*Current activities*	*Mobility aids*
1	M	48	C5	C/D	24	Flouexetine	Walking	Cane, left AFO
2	M	35	T11	A	7	Baclofen Botox (quads) Novotrimnol Vesicare	Brace walking	Forearm crutches HKAFOs manual chair
3	M	52	C5	C	7	GABA Baclofen (oral) Nortripaline	Walking, gym	Cane
4	M	33	C5	C	15	Baclofen (oral)	Gym, yoga, stretching	Manual chair Forearm crutches
5	M	41	T5	B	6	Baclofen (intrathecal) Pariet Citalopram	Walking	Walker HKAFOs manual chair
6	M	54	C6	D	29	Baclofen (oral) Diazepam	Walking	Cane
7	F	54	C5	C	4	Botox (pectoralis)	Standing frame	Power chair walker
8	M	36	T6	C/D	18	NSAIDs	Gym, WC training	Manual chair left AFO forearm crutches

Abbreviations: AFO, ankle foot orthoses; ASIA, American Spinal Injury Association; meds, medication; HKAFOs, hip knee ankle foot orthotic; NSAIDs, non-steroidal anti-inflammatory drugs.
[a]The ASIA system defines the neurological level of injury as the most caudal segment on both sides of the body that tests as normal for both sensory and motor function.

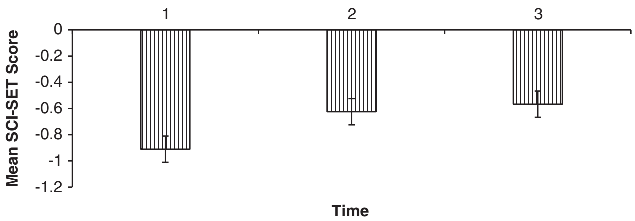

Figure 1 Mean SCI-SET scores. Mean SCI-SET scores over time for visit 1, visit 2 and visit 3. Scores were not significantly reduced between T1 and T3 (P=0.133). Error bars indicate s.e.m.

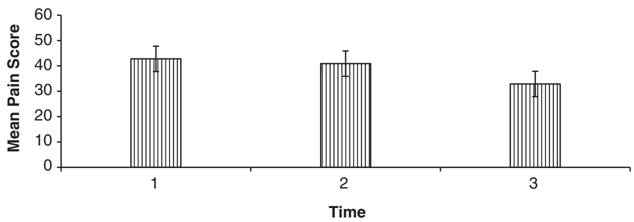

Figure 2 Mean total pain (PTOT) scores total pain mean scores over time for visit 1, visit 2 and visit 3. Scores were significantly reduced (P=0.027) between V1 and V3. Error bars indicate s.e.m.

Pain and fatigue

Pain evaluated with the POQ-VA dropped significantly over time ($P<0.05$). for the three visits: initial 42.75($\pm$8.49), midway 40.88 ($\pm$10.10) and final 32.88($\pm$7.17) (Figure 2). For fatigue, the difference between initial and final visits was not significant, however, the fatigue scores did improve from a mean of 4.2($\pm$0.47) at initial visit to a final level of 3.7($\pm$0.54). No adverse events occurred during this present study during any training session, similar to previous work.[6,10] Participants thoroughly enjoyed the Segway and often wanted to keep it.

DISCUSSION

Spasticity

A dynamic standing program using the Segway may reduce spasticity immediately, and potentially pain and fatigue over time. Whether or not a dynamic standing program using the Segway can reduce spasticity over time remains to be determined. We acknowledge that spasticity can be exacerbated by many events for which we could not control for in this study. Thus, to obtain any decrease in spasticity in a small limited study such as this is encouraging.

Spasticity is not always negative and the SCI-SET is sensitive to both positive and negative effects. Some positive scores were provided pertaining to some form of weight-bearing activity (transfers or walking). This indicates that responses for the SCI-SET may vary based on the whether the primary spasticity involves the upper or lower extremity. Negative SCI-SET scores could reflect the presence of more upper extremity spasticity leading to a greater loss of independence. Conversely, lower-extremity spasticity may be of assistance in weight bearing, thus receiving more positive scores. In this pilot study we did not stratify the data based on upper or lower extremity muscles. In a larger study, this discrimination should be done.

It may be debated that the results from this study are merely due to the fact that these participants were standing on the Segway. Standing frames produce passive stretch for muscles and viscoelastic joint structures, and rely on skeletal support systems to transmit body weight. Although reductions in spasticity have been reported with the use of standing frames,[14–16] these studies relied only on subjective self-report measures. In addition, standing frames have occasionally been implicated in increased spasticity.[16] The theory of standing may not apply here as all of our participants were household ambulators or were already involved in standing programs regularly (Table 1).

Attempts to achieve dynamic stability may potentially override reflex hyperactivity that exacerbates spasms. The vestibulospinal pathways that regulate extensor tone do not require cortical input, and therefore may remain intact in individuals with SCI.[17] Vestibulospinal activity can be initiated by inputs activated by a change in relative head position and/or afferent inputs from the limbs.[18] A standing frame requires relatively little voluntary motor activity or cortical modulation for an individual who is passively supported. Conversely, maintaining a dynamic equilibrium (such as on the Segway) requires significant activation of leg muscles and co-contraction strategies to generate postural adjustments, particularly with respect to a hip control strategy, for which the vestibular system is intimately involved.[18] These dynamic adjustments may modify the descending drive to the spinal cord (for example vestibulospinal) via spino-bulbo-spinal pathways. Descending activity within pathways such as the vestibulospinal system can change or modulate the excitability of spinal reflex pathways involved in spasticity.[19,20]

This same type of response was also considered in a similar study. Lechner *et al*[13] studied 12 participants with SCI (ASIA A) and had them participate in a randomized controlled trial of three, 4-week programs of two sessions per week, 25 min in duration, using three interventions: hippotherapy (therapeutic horse riding), sitting and rocking astride a Bobath roll, and sitting on a rocker board to simulate hippotherapy. Outcomes included the Ashworth scale, Bf-S for well-being, and a self report Visual Analogue Scale (VAS) for spasticity. As per our Segway study, pre/post session measures were done as well as comparisons for long-term effects. Ten muscle groups were measured and added to get an Ashworth Sum Score. They found an immediate decrease in spasticity (Ashworth, VAS and Bf-S) pre and post hippotherapy sessions, but not for the other two interventions. Similar to our study there was no long-term benefit for any intervention.

They suggested that the result was the combination of an inhibiting sitting position and rhythmic movements that produced these benefits. In addition, the horseback movement not only applies a sagittal movement on the patient's pelvis, as the rocking board did, but also a complex 3-dimensional displacement. As spasticity is a malfunctioning of spinal circuits caused by abnormal descending control of spinal pathways and local changes at the spinal level, the walking movement of an able-bodied person causes reciprocal inhibition (by spinal circuitries). The alternating rhythmic movement of subjects' legs and pelvis while sitting on the walking horse may also function as proprioceptive afferent feedback. The constant motion of the Segway may serve the same function.

Pain

Self-evaluations of pain were significantly reduced in all subjects over time (P=0.027). Decreased pain may be a result of positional changes (including muscle stretch and visceral organ realignment), increased postural muscle activation and variations in cutaneous feedback with Segway training. As use of the Segway requires less energy to operate than a manual wheelchair, cane or forearm crutches, we hypothesize that long-term fatigue and pain, which interferes with ADLs, would be reduced using the Segway. Finally, perhaps these notable improvements in pain are attributable not only to a physical effect but also to a positive mental state and socialization experiences, which also have a role in fatigue.

Study limitations

A decrease in spasticity and pain, as well as improvements in sense of overall well-being were observed in a small sample of individuals with SCI. However, ratings of fatigue, the impact of spasticity, and muscle scores over time were not significant. A multi-centre study would be required to provide a larger sample and broaden the generalizability of the results to other regional areas. Our study also did not have a control group. Future work should find an equipoise intervention as a control.

As mentioned previously, all participants could stand or walk; however, we did not record specifically how much was done over the course of the study. In retrospect, the investigators would have asked participants to keep a record of their standing regime in order to fully differentiate the implications of the Segway from their regular standing programs.

Other types of therapy such as stretching programs can help one manage their spasticity, but if one can manage their spasticity while doing other daily tasks, like walking the dog or going to the local shop on a Segway, adherence may increase. Stretching programs are less interesting and functional than the Segway, and hippotherapy is not accessible for most people. We acknowledge the Segway is not affordable for many people and people have suffered severe injuries from its use.[21] The Segway must be used within its bounds and with care, similar to other powered devices. In our work to date, no one has experienced any injury; thus potential benefits may outweigh risks.

CONCLUSION

Dynamic standing using the Segway may provide short-term reductions in spasticity as measured by MAS. However, long-term benefits in spasticity are not as apparent. There is some evidence to suggest that benefits in pain and fatigue may have lasting effects over a month, but further investigations of a longitudinal nature are required to support this idea. Perhaps the Segway introduces a neurostimulus, which overrides spasticity in some capacity. Future research is needed to explore these mechanisms in detail.

DATA ARCHIVING

There were no data to deposit.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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