Case report

Using a mobility assistance dog reduces upper limb effort during manual wheelchair ramp ascent in an individual with spinal cord injury

Dany Gagnon^{1,2}, Marie Blanchet^{1,2}, Valérie Martin-Lemoyne^{1,2}, Claude Vincent^{3,4}, François Routhier^{3,4}, Hélène Corriveau⁵

¹Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR), Institut de Réadaptation Gingras-Lindsay-de-Montréal, Canada, ²School of Rehabilitation, Université de Montréal, Montreal, Canada, ³Centre for Interdisciplinary Research in Rehabilitation and Social Integration (CIRIS), Institut de Réadaptation en Déficience Physique de Québec, Quebec, Canada, ⁴Department of Rehabilitation, Université Laval, Quebec, Canada, ⁵School of Rehabilitation, Université de Sherbrooke, Sherbrooke, Canada

Objective: To compare the mechanical and muscular efforts generated in the non-dominant upper limb (U/L) when ascending a ramp with and without the use of a mobility assistance dog (AD_{Mob}) in a manual wheelchair user with a spinal cord injury.

Method: The participant ascended a ramp at natural speed using his personal wheelchair with (three trials) and without (three trials) his AD_{Mob}. Movement parameters of the wheelchair, head, trunk, and non-dominant U/L (i.e. hand, forearm, and arm segments) were recorded with a motion analysis system. The orthogonal force components applied on the hand rims by the U/Ls were computed with instrumented wheels. Muscular activity data of the clavicular fibers of the pectoralis major, the anterior fibers of the deltoid, the long head of the biceps brachii, and the long head of the triceps brachii were collected at the non-dominant U/L.

Results: During uphill propulsion with the AD_{Mob}, the total and tangential forces applied at the non-dominant handrim, along with the rate of rise of force, were reduced while mechanical efficiency was improved compared to uphill propulsion without the AD_{Mob}. Similarly, the resultant net joint movements (wrist, elbow, and shoulder) and the relative muscular demands (biceps, triceps, anterior deltoid, pectoralis major) decreased during uphill propulsion with an AD_{Mob} versus without an AD_{Mob}.

Conclusion: Propelling uphill with the assistance of an AD_{Mob} reduces U/L efforts and improves efficiency compared to propelling uphill without its assistance in a manual wheelchair user with a spinal cord injury.

Keywords: (MeSH): Spinal cord injuries, Paraplegia, Assistance dog, Rehabilitation, Activities of daily living, Assistive technology, Task performance and analysis, Upper extremity, Wheelchair

Introduction

Developing basic and advanced manual wheelchair skills is essential for manual wheelchair users (MWUs), especially those who have sustained a spinal cord injury (SCI), to safely perform their daily routines as independently and efficiently as possible.¹ While carrying out their daily routines, MWUs must constantly cope with challenges in their natural or architectural environments when navigating with their

wheelchair. The challenges MWUs frequently encounter include such obstacles as steep hills or ramps with slopes that exceed building codes in their natural environments. Both of these situations force the upper limbs (U/Ls), especially the shoulders, to generate additional efforts during propulsion that may contribute to the development, persistence, or exacerbation of secondary U/L musculoskeletal impairments, pain, or fatigue frequently reported in this population.² Moreover, these situations may jeopardize the safety of MWUs due to the high risk of tipping backward and, in turn, may cause fall-related injuries.^{3,4}

Correspondence to: Dany Gagnon, School of Rehabilitation, Université de Montréal, Pavillon 7077 Avenue du Parc, PO Box 6128, Station Centre-Ville, Montreal, Quebec, Canada H3C 3J7.
Email: dany.gagnon.2@umontreal.ca

Owing to these potential problems and the need to adopt preventive strategies, rehabilitation professionals occasionally recommend the use of an assistance dog for mobility (AD_{Mob}) to facilitate manual wheelchair propulsion and to improve manual wheelchair skills, particularly community-level skills such as uphill propulsion (i.e. ramp ascent) and other wheelchair-related tasks requiring good skills (e.g. opening doors, carrying bags, picking up objects from the floor).^{5,6} Approximately 55 AD_{Mob} have been attributed yearly to individuals living with sensorimotor impairments or physical disabilities in Quebec since 1993 by MIRA Foundation, an internationally recognized organization (www.mira.ca).⁷ Among these AD_{Mob}, almost 35% of them are routinely solicited to assist these individuals with manual wheelchair propulsion.⁸

When assisting MWUs with propulsion, the AD_{Mob} wears a harness, often custom-made by the organization providing the AD_{Mob}, which is wrapped around the dog's shoulders and trunk. A U-shaped aluminum frame is anchored to this harness caudally from the dog's shoulder joints and points backward to hook onto a band attached anteriorly to each side of the wheelchair frame to pull the wheelchair from the middle front portion. Positioning the AD_{Mob} in such a position when assisting with wheelchair propulsion, as opposed to on the side of the wheelchair as frequently observed, is expected to solicit symmetric effort from the AD_{Mob}, and to reduce its risk of developing secondary impairments, especially those affecting its hind limbs (e.g. hip joint osteoarthritis). The use of an AD_{Mob} may reduce U/L efforts generated by MWUs during propulsion, especially during uphill propulsion which requires additional efforts compared to level ground propulsion.^{9,10} However, no clear evidence guides rehabilitation professionals because no study has yet quantified the effects of using of an AD_{Mob} on the U/L efforts via a comprehensive biomechanical approach when propelling uphill. Moreover, the lack of evidence may also translate into discrepancies as some funding agencies may consider the AD_{Mob} and the pet care-related fees as a reimbursable assistive technology/technical aid, whereas others may not.

This study aims to compare the mechanical and muscular efforts generated in the non-dominant U/L when ascending a ramp with and without the use of an AD_{Mob} in a MWU with a SCI. It was hypothesized that the mechanical and muscular efforts required to ascend a ramp would be significantly reduced when using an AD_{Mob} in comparison to performing this task without the use of an AD_{Mob}.

Methods

Participant and his personal mobility assistance dog

A 26-year-old man (weight = 59.5 kg, height = 1.83 m) who sustained a complete T7 SCI more than 5 years ago was recruited. This participant uses a manual wheelchair as his primary means of mobility, has the ability to independently propel uphill, and has been paired with his AD_{Mob} (breed: Labernese; age, 6.8 years; weight, 38 kg) for almost 4.7 years. A subjective assessment and objective clinical examinations that this participant presented no significant signs or symptoms of U/L impairments (overall score of 1.88/10 on the Wheelchair User Shoulder Pain Index and 2.6/10 for the ramp ascent item on the Wheelchair User Shoulder Pain Index).^{11,12} He also did not present any other condition that might have altered his ability to propel a manual wheelchair. Note that the AD_{Mob} in this study, trained by MIRA Foundation, was paired with the participant according to specific criteria to be met during a specialized breeding program, a 1-year stay in a foster home during which health and behavior screening are routinely completed, a rigorous 5-month structured training program during which most of the time is dedicated to task-specific training (e.g. wheelchair propulsion and wheelchair-related task assistances), and finally a full-time assignment adjustment period of 3 weeks (full-time) with whom it is paired. Ethical approval was obtained from the Research Ethics Committee of the Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR-633-0711). After both human and animal (e.g. familiarity, comfort, and workload associated with the experimental tasks) ethical practices were confirmed. The participant read and signed the informed consent form prior to initiating this assessment at the Pathokinesiology Laboratory located at the Institut de réadaptation Gingras-Lindsay-de-Montréal.

Laboratory assessment

Wheelchair ramp ascent

Following a familiarization period, the participant ascended a portable ramp (slope = 8.5°, length = 4.0 m, width = 1.2 m, height = 0.6 m) at natural speed using his personal wheelchair with the assistance of his AD_{Mob} (three trials) and without the assistance of his AD_{Mob} (three trials). Before initiating the ramp ascent task, the wheelchair was positioned behind a start line located 1 m before the start of the ramp. Upon completion of the ramp ascent, the wheelchair stopped on a portable dock (length = 1.8 m, width = 1.3 m, height = 0.6 m) attached to the ramp. Although the

8.5° slope in this study exceeds the recommendations of many building codes, it represents a slope routinely encountered in a natural environment, and to a lesser extent, in an architectural environment during everyday wheelchair propulsion.

Kinematics

Kinematic parameters of the wheelchair, head, trunk, and non-dominant U/L (i.e. hand, forearm, and arm segments) were recorded at 60 Hz using an Optotrak motion analysis system (NDI, Waterloo, ON, Canada), synchronizing four camera units. This system tracked the 3D coordinates of three non-collinear skin-fixed light emitting diodes attached to the wheelchair and to each body segment of interest to model each of the rigid segments described above. Specific wheelchair reference points and anatomical bony landmarks were also digitized to further define principal axes of segments and articular centers. The marker coordinates were smoothed with a fourth-order Butterworth zero-lag filter using a cut-off frequency of 6 Hz. Custom-made programs quantified angular displacements, velocities and acceleration of the wheelchair, trunk, U/L, and head segments.

Kinetics

Handrim kinetics: SmartWheel instrumented wheels were fitted onto the participant's wheelchair to capture, at 240 Hz, the x , y , and z orthogonal force components (F_x , F_y , F_z) applied to the handrims by the U/Ls.¹³ These instrumented wheels did not considerably alter the participant's wheelchair characteristics (e.g. width, weight, wheel dimension, and handrim position), aside from the increased total weight of the wheelchair (SmartWheel = 4.9 kg/wheel). The magnitude of the total force (F_{tot}) applied to the handrims as well as the magnitude of the tangential force (F_{tang}) directly contributing to the wheelchair's forward movement were calculated at the non-dominant U/L during the push phase. The mechanical effective force ($MEF = F_{tang}^2 / F_{tot}^2$) and the rate of rise of the F_{tot} were also calculated during this phase.

Upper limb kinetics: The handrim kinetics measured underneath the non-dominant U/L, the U/L kinematic data, and the anthropometric data recorded were entered into a 3D inverse dynamic algorithm.^{14,15} The magnitudes of the resultant net joint movements were estimated at the wrist, elbow, and shoulder joints of the non-dominant U/L during the push phase.

Electromyography

Muscular activity data of the clavicular fibers of the pectoralis major, the anterior fibers of the deltoid, the long head of the biceps brachii, and the long head of the

triceps brachii were collected at the non-dominant U/L at a sampling frequency of 1200 Hz using a portable Telemyo 900 system (Noraxon USA Inc., Scottsdale, Arizona, USA). All electromyography (EMG) data collected were visually inspected following baseline noise removal and thus filtered using a fourth-order Butterworth bandpass filter with cut-off frequencies set at 30 and 500 Hz. Then, the EMG patterns were full-wave rectified before they were filtered with a 6 Hz low-pass filter to generate linear envelopes. All EMG signal processing was performed digitally with a custom MATLAB program. Lastly, in order to calculate the relative muscular utilization ratio (%MUR_{EMG}) during the push phase, the amplitude of the EMG linear envelope of each muscle recorded during the wheelchair ramp ascent tasks was amplitude-normalized with the best estimate of the maximum EMG values. These maximum EMG values were obtained from two 5-second static maximal voluntary contractions completed in accordance with a standardized protocol prior to the ramp ascent tasks.¹⁶ The EMG_{max} reflects the highest mean EMG values reached over consecutive periods of 0.5-second intervals computed during maximal voluntary contractions recorded using a custom MATLAB program. Note that surface EMG only allows for monitoring of U/L superficial muscles and may not represent the EMG activity of the muscles lying underneath those studied.

Data reduction and statistics

A time-normalized profile (100%) was generated for all outcomes measured during the last three consecutive strokes (push phase only) at the non-dominant U/L while ascending the ramp for each of the three trials completed with and without the use of the AD_{Mob}. A mean + 1 standard deviation (SD) time-normalized profiles for the propulsion uphill was calculated with (3 strokes × 3 trials = 9 strokes) and without the use of the AD_{Mob} (3 strokes × 3 trials = 9 strokes). For each of these strokes, the mean and maximum values were computed to generate mean ± 1SD values for the propulsion uphill with and without the AD_{Mob}. To quantify the effect of using an AD_{Mob}, a percentage of change was ultimately computed. The rationale for only reporting the non-dominant U/L effort, generally the weakest U/L, was based on the notion that it is likely the most limiting factor of performance (relative demand) when propelling uphill on a narrow ramp where near-symmetric forces (absolute demand) are expected to be applied to the handrims by both U/Ls to maintain a constant direction/trajectory, particularly during the most demanding phase (propulsion phase).

Results

Handrim kinetics

The mean ($\pm$ SD) profiles of the F_{tot} , F_{tang} , and MEF when propelling uphill with and without the AD_{Mob} are illustrated in Fig. 1. When propelling uphill with the use of the AD_{Mob}, the mean ($54.7 \pm 5.8.7$ N versus 83.5 ± 4.7 N) and maximum F_{tot} (72.5 ± 6.1 N versus 134.5 ± 6.4 N) were 34.5 and 46.1%, respectively, lower than without the AD_{Mob}. When propelling uphill with the use of the AD_{Mob}, the mean (42.0 ± 4.3 N versus 57.0 ± 4.7 N) and maximum F_{tang} (65.6 ± 6.9 N versus 103.5 ± 7.7 N) were 26.3 and 36.6%,

respectively, lower than with the use of the AD_{Mob}. As for the mean MEF, it was 29.8% higher when propelling uphill with an AD_{Mob} (MEF = $61 \pm 6.67\%$) than when doing so without the AD_{Mob} (MEF = $47 \pm 6.0\%$). Comparable maximum rate of rise of F_{tot} was calculated around the impact with the handrim (greatest magnitude) when propelling uphill with and without the AD_{Mob} (1652.9 ± 189.2 N/second versus 1585.5 ± 283.9 N/second), whereas it was attenuated by 73.0% towards the end of the propulsion phase when using the AD_{Mob} (145.4 ± 61.4 N/second versus 539.1 ± 173.2 N/second).

Figure 1 Time-normalized mean (SD) profiles, as well as overall mean and maximum values of the total force and the tangential force applied to the non-dominant handrim, as well as mechanical efficiency during uphill propulsion with and without the use of an assistance mobility dog. Solid and dotted lines represent mean and SD values, respectively.

Figure 2 Time-normalized mean (SD) profiles, as well as overall mean and maximum values of the net joint movements measured at the non-dominant wrist, elbow, and shoulder during uphill propulsion with and without the use of an assistance mobility dog. Solid and dotted lines represent mean and SD values, respectively.

Upper limb moments

The mean ($\pm$ SD) profiles of the net resultant movements estimated at the non-dominant wrist, elbow, and shoulder when propelling uphill with and without the AD_{Mob} are illustrated in Fig. 2. The mean net joint movements were reduced by 60.5 (6.0 ± 0.6 Nm versus 15.1 ± 2.0 Nm), 45.0 (15.2 ± 9.1 Nm versus 27.6 ± 2.7 Nm), and 36.9% (21.2 ± 1.6 Nm versus 33.6 ± 3.0 Nm), whereas the maximal movements were reduced by 56.9 (10.8 ± 1.8 Nm versus 25.1 ± 4.3 Nm),

34.7 (25.7 ± 2.3 Nm versus 39.4 ± 6.0 Nm), and 32.3% (32.1 ± 3.8 Nm versus 47.4 ± 4.3 Nm) at the wrist, elbow, and shoulder, respectively.

Relative muscular utilization ratio

The mean ($\pm$ SD) electromyographic profiles of the biceps brachii, triceps brachii, anterior deltoid, and pectoralis major at the non-dominant U/L when propelling uphill with and without the AD_{Mob} are illustrated in Fig. 3. The mean %MUR_{EMG} were reduced by 38.5

Figure 3 Time-normalized mean (SD) profiles, as well as overall mean and maximum values of the relative muscular utilization ratio (%) measured at the non-dominant biceps, triceps, anterior deltoid, and pectoralis major during uphill propulsion with and without the use of an assistance mobility dog. Solid and dotted lines represent mean and SD values, respectively.

($11.9 \pm 1.5\%$ versus $19.3 \pm 3.4\%$), 59.5 ($4 \pm 0.6\%$ versus $10.1 \pm 1.4\%$), 26.6 ($11.2 \pm 1.7\%$ versus $15.2 \pm 3.6\%$), and 44.9% ($6.5 \pm 1.2\%$ versus $11.8 \pm 1.5\%$), whereas the maximum %MUR_{EMG} were reduced by 28.8 ($26.9 \pm 4.1\%$ versus $37.8 \pm 7.0\%$), 64.3 ($12.5 \pm 2.7\%$ versus $35.0 \pm 4.7\%$), 44.7 ($21.0 \pm 3.1\%$ versus $38.0 \pm 10.5\%$), and 48.2% ($12.9 \pm 1.6\%$ versus $24.9 \pm 4.0\%$) at the non-dominant biceps brachii, triceps brachii, anterior deltoid, and pectoralis major, respectively.

Discussion

Beneficial effects of using a mobility assistance dog

The results of this study support the hypothesis that the use of an AD_{Mob} considerably reduces U/L effort (i.e. reduced force applied at the handrim and lower net joint movement and relative muscular demand at the U/L) when propelling uphill in a MWU with SCI. Unexpectedly, the results of this study also demonstrate that mechanical efficiency is improved when propelling uphill with an AD_{Mob}. Both of these key findings confirm that the use of an AD_{Mob} when propelling forward in a challenging natural or architectural environment, particularly during uphill propulsion, may facilitate independent performance of this task, limit the development of fatigue, or reduce U/L risk exposure. Despite all these beneficial effects, caution is nevertheless advised with respects to potential adverse effects (e.g. reduced physical fitness and reduced U/L, scapulohumeral, scapulothoracic, and trunk muscle strength) associated with the long-term use of an AD_{Mob} and to the potentially permanent and debilitating long-term health effects on the AD_{Mob}. Hence, rehabilitation professionals need to carefully assess whether the potential beneficial effects outweigh the possible adverse effects before recommending the use of an AD_{Mob} in MWUs. Furthermore, they also need to simultaneously consider the pros and cons of using other technological adaptations, such as handrim-activated power-assisted wheels for example, to facilitate manual wheelchair propulsion when assessing the need for an AD_{Mob}.¹⁷

Limitations of this study

Given the design of this study, the level of evidence remains low and careful interpretation of the results is required. However, this study represents the first attempt to quantify the effects of using an AD_{Mob} on U/L efforts during uphill propulsion using a biomechanical approach. These preliminary results are also encouraging as they confirm the feasibility of quantifying the effects of using an AD_{Mob} on U/L efforts

during manual wheelchair propulsion and related activities within a larger cohort of participants using various research designs. Such studies are needed to strengthen the current level of evidence. An attempt to measure the gross pulling strength of assistance mobility dogs versus the magnitude of assistance these dogs can truly provide MWUs is also advised in the future.

Conclusion

The use of an AD_{Mob} reduces U/L efforts (i.e. handrim forces, net joint movements, and relative muscular utilization) and improves efficiency (i.e. MEF) when propelling uphill compared to the doing the same task without assistance in a MWU with SCI.

Acknowledgments

The authors acknowledge Guillaume Desroches (post-doctoral fellow), Youssef El Khamlichi (research associate), and Philippe Gourdou (research associate) for their endless assistance during data collection, processing, and analysis. Special thanks are also extended to Prof. Michel Y. Tousignant and Prof. Lise Poissant for their intellectual contribution to the project. Dany Gagnon holds a Junior 1 Research Career Award from the Fonds de la recherche en santé du Québec (FRSQ) and is a member of the SensoriMotor Rehabilitation Research Team funded by the Canadian Institute of Health Research (CIHR). Marie Blanchet holds a Summer Undergraduate Student Research Award from the Institute of Musculoskeletal Health and Arthritis of the CIHR. The project was supported by the Traumatology Research Consortium of the Fonds de la recherche en santé du Québec (FRSQ). The equipment and material required for the research conducted at the Pathokinesiology Laboratory was financed, in part, by the Canada Foundation for Innovation (CFI).

References

- Hosseini SM, Oyster ML, Kirby RL, Harrington AL, Boninger ML. Manual wheelchair skills capacity predicts quality of life and community integration in persons with spinal cord injury. *Arch Phys Med Rehabil* 2012;93(12):2237–43.
- Consortium for Spinal Cord Medicine Preservation of upper limb function following spinal cord injury: a clinical practice guideline for health-care professionals. *J Spinal Cord Med* 2005;28(5):434–70.
- Calder CJ, Kirby RL. Fatal wheelchair-related accidents in the United States. *Am J Phys Med Rehabil* 1990;69(4):184–90.
- Xiang H, Chany AM, Smith GA. Wheelchair-related injuries treated in US emergency departments. *Inj Prev* 2006;12(1):8–11.
- Collins DM, Fitzgerald SG, Sachs-Ericsson N, Scherer M, Cooper RA, Boninger ML. Psychosocial well-being and community participation of service dog partners. *Disabil Rehabil Assist Technol* 2006;1(1–2):41–8.
- Allen K, Blascovich J. The value of service dogs for people with severe ambulatory disabilities: a randomized controlled trial. *JAMA* 1996;275(13):1001–6.

- 7 MIRA Foundation. Service (assistance) dog for person with mobility impairment. Sainte-Madeleine, Québec: MIRA Foundation Inc.; 2011.
- 8 Vincent C, Joyal I, Gagnon D, Routhier F. Étude rétrospective transversale de l'utilisation d'un chien d'assistance à la motricité au Québec. Quebec City: Institut de réadaptation en déficience physique de Québec; 2012.
- 9 Yang YS, Koontz AM, Yeh SJ, Chang JJ. Effect of backrest height on wheelchair propulsion biomechanics for level and uphill conditions. *Arch Phys Med Rehabil* 2012;93(4):654–9.
- 10 Richter WM, Rodriguez R, Woods KR, Axelson PW. Stroke pattern and handrim biomechanics for level and uphill wheelchair propulsion at self-selected speeds. *Arch Phys Med Rehabil* 2007; 88(1):81–7.
- 11 Curtis KA, Roach KE, Applegate EB, Amar T, Benbow CS, Genecco TD, *et al.* Development of the Wheelchair User's Shoulder Pain Index (WUSPI). *Paraplegia* 1995;33(5): 290–3.
- 12 Curtis KA, Roach KE, Applegate EB, Amar T, Benbow CS, Genecco TD, *et al.* Reliability and validity of the Wheelchair User's Shoulder Pain Index (WUSPI). *Paraplegia* 1995;33(10):595–601.
- 13 Cooper RA. SMARTWheel: from concept to clinical practice. *Prosthet Orthot Int* 2009;33(3):198–209.
- 14 Desroches G, Dumas R, Pradon D, Vaslin P, Lepoutre FX, Cheze L. Upper limb joint dynamics during manual wheelchair propulsion. *Clin Biomech (Bristol, Avon)* 2010;25(4):299–306.
- 15 Dumas R, Aissaoui R, de Guise JA. A 3D generic inverse dynamic method using wrench notation and quaternion algebra. *Comput Meth Biomech Biomed Eng* 2004;7(3):159–66.
- 16 Montgomery J, Hislop H, Connelly B, Daniels L. *Daniel's and Worthingham's muscle testing: techniques of manual examination*. WB Saunders Company, Philadelphia, PA, 2007.
- 17 Kloosterman MG, Snoek GJ, van der Woude LH, Buurke JH, Rietman JS. A systematic review on the pros and cons of using a pushrim-activated power-assisted wheelchair. *Clin Rehabil* 2013; 27(4):299–313.