RESEARCH REPORT

External Research Program

Effect of Snow and Ice on Exterior Ramp Navigation by Wheelchair Users

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Effect of Snow and Ice on Exterior Ramp Navigation by Wheelchair Users

Final Report for
Canada Mortgage and Housing External Research Program

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1. Executive Summary

Winter is a defining season for Canadians. For people with disabilities, winter presents new obstacles for mobility and access to facilities. Wheelchair users are particularly affected by snow and ice conditions since previously accessible facilities become inaccessible. Unfortunately, no quantitative research existed to make informed decisions regarding mobility and exterior ramps in winter conditions. This study is the first quantitative biomechanical analysis of wheelchair mobility on ramps under snow and ice conditions.

Eleven manual wheelchair users who typically self-propel their wheelchair in winter were recruited through The Ottawa Hospital Rehabilitation Centre. An adjustable ramp was modified to provide a safe testing environment at 1:10, 1:12, 1:16 slopes. Two winter scenarios were evaluated, packed snow and "packed snow with a freezing rain cover and traction grit". All testing took place at the National Research Council, Centre for Surface Transportation Technology, which provided a world-class, controlled environment for creating consistent winter conditions. Subjects navigated the ramp at each slope and at each condition. Motion tracking, video, and questionnaire data were collected to assess biomechanics and subject perceptions.

This study confirmed that independent navigation cannot to be assumed for all conditions and ramp grades that are accepted under current building codes. In terms of ramp grade, all subjects were able to complete the ice-grit conditions independently at all ramp slopes. Snow conditions produced a much different scenario across ramp grades, with the 1:10 grade being insurmountable for many subjects without assistance. Project outcomes can be summarized as:

- The 1:16 grade is preferred for winter ramp navigation, based on the lower number of difficulties and lowest times to ascend the ramp.
- For snow conditions, the transition area from level ground to the first 2m of ramp incline was the most difficult to traverse, for both ascent and descent. Guidelines for design and maintenance of this area are recommended to improve accessibility and independence.
- For ice-grit ramp navigation, two-railing propulsion is a preferred strategy due to enhanced trajectory control and reducing the potential for wheel slip problems.
- Backwards ramp ascent for snow conditions should be considered for people with sufficient shoulder and trunk range of motion.
- Two handrails are recommended for exterior ramps, for propulsion and extraction from ruts and other snow-related obstacles. Important factors include allowing unobstructed grip throughout the ramp length and ensuring railings that are free of snow and ice, etc.
- The amount of grit required and the effective time (i.e., time when embedded grit becomes much less effective) should be addressed in further research.
- Front wheels typically available with manual wheelchairs are not designed for soft snow conditions. Few option exist that attempt to address this need.

As the first biomechanical evaluation of wheelchair ramp navigation, the outcomes from this study provide a better understanding of wheelchair user strategies for dealing with ramps in winter. In addition to the information directly related to wheelchair mobility, this study demonstrated a viable quantitative analysis environment for future assessments of human interaction with external residential pathways in Canadian weather conditions.

2. Résumé

L'hiver fait partie de la vie des Canadiens. Pour les personnes handicapées, l'hiver comporte son lot de problèmes de mobilité et d'accès aux installations. Les utilisateurs de fauteuils roulants sont particulièrement touchés par les conditions glacées et enneigées, puisque des installations antérieurement accessibles deviennent inaccessibles. Malheureusement, il n'existait aucune recherche quantitative permettant de prendre des décisions éclairées en ce qui concerne la mobilité sur rampes d'accès extérieures en conditions hivernales. L'étude est la première analyse quantitative biomécanique de la mobilité des fauteuils roulants sur les rampes d'accès dans des conditions enneigées ou glacées.

On a recruté, par l'intermédiaire du Centre de réadaptation de l'Hôpital d'Ottawa, onze utilisateurs de fauteuils roulants manuels. Une rampe d'accès ajustable a été modifiée de façon à offrir un cadre d'essai sécuritaire à des pentes de 1:10, 1:12 et 1:16. Deux scénarios hivernaux ont été évalués, « neige damée » et « neige damée avec couvert de pluie verglaçante et ajout de sable antidérapant ». Tous les essais ont eu lieu au Centre de technologie des transports de surface du Conseil national de recherches du Canada, dans un environnement contrôlé de classe mondiale qui a permis de recréer des conditions hivernales constantes. On a demandé aux participants de se déplacer sur la rampe à chacune des pentes et dans chacune des conditions. On a recueilli des données sur les déplacements, et au moyen de vidéos ainsi que de questionnaires, dans le but d'évaluer l'aspect biomécanique et les perceptions des participants.

L'étude a confirmé que la manœuvre autonome n'est peut-être pas possible dans toutes les conditions et à toutes les pentes qui sont actuellement acceptées dans les codes du bâtiment. En ce qui concerne les pentes des rampes d'accès, tous les participants ont réussi à se déplacer seuls en conditions glacées avec ajout de sable antidérapant à toutes les pentes. Les conditions enneigées ont produit des résultats très différents à toutes les pentes, et la pente 1:10 s'est avérée infranchissable pour de nombreux participants non aidés. Voici le sommaire des résultats de l'étude :

- La pente 1:16 est la plus facile pour les déplacements en hiver : elle a présenté le moins de difficultés et les participants l'ont gravie plus rapidement que les autres pentes.
- En conditions enneigées, la zone de transition entre le sol plat et les 2 premiers mètres du plan incliné a été la plus difficile à manœuvrer, à la montée et à la descente. Des directives pour la conception et l'entretien de cette zone sont recommandées afin d'améliorer l'accessibilité et l'autonomie.
- En ce qui concerne les déplacements en conditions glacées avec ajout de sable antidérapant, la propulsion au moyen de deux mains courantes est la stratégie préférée parce qu'elle permet une meilleure maîtrise de la trajectoire et réduit les risques de dérapage.
- L'ascension à reculons en conditions enneigées devrait être envisagée pour les personnes capables d'effectuer une gamme suffisante de mouvements des épaules et du torse.

- Deux mains courantes sont recommandées pour les rampes extérieures, pour permettre aux utilisateurs de se propulser, de se sortir des ornières et de franchir d’autres obstacles liés à la neige. Parmi les facteurs importants, notons l’absence d’éléments gênant la saisie des mains courantes sur toute leur longueur, et l’absence de neige ou de glace sur les mains courantes.
- La quantité de sable antidérapant nécessaire et sa durée effective (c.-à-d. le temps après lequel le sable incorporé à la glace devient moins efficace) devraient faire l’objet d’une autre étude.
- Les roues avant des fauteuils manuels habituels ne sont pas conçues pour les conditions de neige molle. Il existe peu d’options pour répondre à ce besoin.

L’étude constitue la première évaluation biomécanique de la manœuvre en fauteuil roulant sur rampe d’accès. Ses résultats offrent une meilleure compréhension des stratégies employées pour les déplacements sur rampes d’accès en hiver. En plus d’enrichir nos connaissances sur la mobilité des fauteuils roulants, l’étude a conçu un environnement d’analyse quantitative viable qui pourra servir à des évaluations futures des déplacements humains sur les sentiers résidentiels extérieurs en conditions climatiques canadiennes.

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3. Abstract

Wheelchair users are particularly affected by snow and ice conditions since previously accessible facilities become inaccessible. This study is the first quantitative analysis of wheelchair mobility on ramps under winter conditions. Eleven manual wheelchair users ascended an exterior ramp at 1:10, 1:12, 1:16 slopes, under packed snow and “packed snow with a freezing rain cover and traction grit” conditions. Vicon motion tracking, video, and questionnaire data were collected to assess biomechanics and subject perceptions. This study confirmed that independent navigation cannot be assumed for all conditions and ramp grades that are accepted under current building codes. All subjects were able to complete the ice-grit conditions independently at all ramp slopes. For snow conditions, the 1:10 grade was insurmountable for many subjects without assistance. The 1:16 grade was preferred for winter ramp navigation. For snow conditions, the transition area from level ground to the ramp incline was the most difficult to traverse. Backwards ramp ascent should be considered for people with sufficient shoulder and trunk range of motion. For ice-grit ramp navigation, two-railing propulsion was preferred due to enhanced trajectory control and reduced wheel slip problems. The amount of grit required and the effective time (i.e., time when embedded grit becomes much less effective) should be addressed in further research. Typical front wheels are not designed for soft snow conditions and few option exist that attempt to address this need. As the first biomechanical evaluation of wheelchair ramp navigation, the outcomes from this study provide a better understanding of wheelchair user strategies for dealing with ramps in winter.

Les utilisateurs de fauteuil roulant sont particulièrement sensibles aux conditions de neige et de glace, car elles limitent soudainement leur accès aux endroits déjà accessibles. Cette recherche est la première analyse quantitative portant sur la mobilité en fauteuil roulant sur les rampes sous des conditions hivernales. Onze utilisateurs de fauteuil roulant manuel ont négocié une rampe à des ratios de 1:10, 1:12 et 1:16, recouverte de ‘neige damée’ puis de ’neige damée verglacée avec gravier’. À l’aide de détecteurs de mouvement Vicon, de vidéos et d’un questionnaire, des données ont été colligées afin d’évaluer les perceptions des sujets et leurs biomécaniques. Cette étude confirme qu’une indépendance à l’ascension ne peut être atteinte sous toutes conditions hivernales et des niveaux de pente de rampe présentement accepter par le code de construction. Sous les conditions de glace-gravier, tous les candidats ont pu compléter la navigation quelque soit la pente de la rampe. Sous les conditions de neige, le ratio 1:10 était insurmontable pour plusieurs sujets, demandant une assistance physique pour le compléter. Sous cette condition, la transition entre la surface plane et le début de la montée était l’étape la plus difficile à franchir. Pour les utilisateurs ayant l’amplitude articulaire au niveau des épaules et du tronc, la montée à reculons s’est avérée une très bonne alternative. Pour la navigation glace-gravier, l’ascension à l’aide des deux mains courante de la rampe a été privilégiée, donnant plus de contrôle au niveau de la direction du fauteuil roulant tout en évitant les problèmes de glissement des roues. La quantité de gravier et son temps d’efficacité (le gravier s’introduisant graduellement dans la glace) devraient être étudiés lors d’une future recherche. De même, la majorité des roues avant ne sont pas construites en fonction de la neige et peu d’alternatives existent pour adresser ce besoin. Comme première étude biomécanique sur la navigation d’une rampe, les résultats obtenus procurent aux utilisateurs en fauteuil roulant des stratégies afin de négocier les difficultés d’une rampe en hiver.

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6. Introduction

Winter represents the most difficult season for people with mobility deficits [1]. These difficulties include slips, falls, increased walking effort, and snow-ice wheelchair obstructions. Considering the amount of time Canadians spend in winter, a remarkably small amount of literature exists on non-sporting winter activities. As a result, guidelines and standards for buildings are predominately based on “dry-land” studies. In the case of residential access ramps, anecdotal feedback from wheelchair users identifies problems with winter accessibility due to the snow-ice surface properties.

Ramps and motorized lifts are the predominate means for wheelchair users to access buildings with raised doorways or multiple floors [2-6]. Considering that Canadian housing designs must accommodate for the spring melt-down, the majority of houses have access doors above ground level. For exterior entry, the 1:12 slope ramp is the most frequently recommended guideline for building accessibility, although a 1:20 slope is considered most appropriate for all wheelchair users [7]. The application of ramp standards/guidelines remain inconsistent [7-9].

Research on manual wheelchair mobility on ramps has shown that young wheelchair users are capable of ascending ramps up to a 1:8 slope, in dry controlled conditions [10-11]. However, as noted by Rousseau et al. [11], the effects of snow, ice, and rain have not been considered in these studies. Most studies reported increased physical demands as ramp slope increases past 1:20. Even at a 1:20 ramp slope, Sabick and Kotajarvi reported upper-extremity joint moments over 30% of the user’s capacity [12]. Kulig et al. [15] showed that shoulder forces and moments more than doubled when ascending an eight-degree incline with a wheelchair.

Research and consumer feedback on slopes steeper that 1:12 is not conclusive. Rousseau et al. [11] indicated that a 1:10 slope was a viable alternative since propulsive forces exerted on the wheelchair rims were not substantially different than forces at a 1:12 slope. However, Rousseau’s study involved able-bodied subjects who may not have the physical limitations found in typical wheelchair users (i.e., decreased range of motion, balance, muscular dysfunction, etc.). In pilot testing for this CMHC project, we setup the ramp with the beginning section at 1:12 and the last section at 1:10. Subjective feedback from testers reported a considerable increase in exertion when moving to the steeper grade. No studies existed that provide biomechanical data on wheelchair propulsion in winter conditions.

Winter is recognized as a mobility inhibitor for most physical disabilities [16-17]. People with spinal cord injuries in Japan reported that “wheels and casters were very slippery on the snow and ice, casters were easily buried in the snow, and wheelchair rims were very cold to handle. It was also pointed out that exposure to cold weather induced physical problems such as muscle spasticity, pain, and numbness of lower extremities.” [18]

In the consumer literature, a qualitative analysis of nine powered wheelchairs while ascending and descending a 10-degree ramp slope with 7.5 cm snow cover was performed by Smith [19]. All powered chairs were able to ascend and descend the ramp; however, control of mid and front-wheel drive chairs was difficult. The investigator indicated that slopes greater than 10 degrees would be very difficult to negotiate in winter.

Many people with disabilities and the elderly stay in their house rather than risk driving their wheelchairs outside when winter precipitation creates a potentially unsafe environment. This can lead to social isolation and related psychosocial problems. Better information on ramp design and ramp negotiation strategies will help educate wheelchair users, health professionals, and builders to create a safe and accessible environment.

The qualitative and related research on winter wheelchair propulsion does not provide adequate information for decision-making regarding residential ramps during winter. This report describes research that provides evidence-based recommendations for builders, homeowners, and people with disabilities when providing ramp-based access to the home. This study is the first quantitative biomechanical analysis of wheelchair mobility on ramps under snow and ice conditions.

7. Significance to Housing

For people with disabilities, access to residences is an important social and practical issue. This importance is reflected in past work that resulted in guidelines for ramp design [4-5]. While studies on manual wheelchair ramp use in dry-summer environments have been beneficial, a large knowledge gap exists for residential ramp use during winter. Closing this gap is especially important for Canadians with disabilities and the elderly.

This report begins to fill the knowledge gap regarding residential access during winter. The biomechanical analysis of wheelchair users on ramps provides quantitative information that can be used for decision making when winter conditions must be considered. For example, a recent study funded by CMHC concluded that a 1:10 ramp slope is an alternative for cases with lack of space [12]. However, qualitative feedback from wheelchair users and occupational therapists question whether a 1:10 slope can be safely navigated in snow/snow-ice conditions. For Canada's elderly and disabled populations, studies on mobility in winter will greatly enhance their ability to safely interact with their environment.

Figure 1: Typical exterior wheelchair ramp in winter conditions.

This project used a full-scale setup that produced "real-world" results that are superior to wheelchair ergometer studies. In addition, people with disabilities who manually propel their wheelchairs in winter were recruited as subjects. Therefore, project outcomes are directly transferable to the target population.

In addition, to identifying problems with ramp design, this project helps with identifying successful strategies for navigating ramps in winter. The project outcomes can be used to guide therapists who train wheelchair users to achieve optimal mobility for their conditions.

A frequently overlooked aspect is winter maintenance of ramps and other residential access devices. While instructions to keep ramps and walkways clear are given to wheelchair users and caregivers, maintenance is often a problem [1]. The outcomes from this study provide evidence that can be used for educating consumers, homeowners, and residential management companies regarding the impact of snow and ice on safe mobility.

In terms of housing construction and design, this research provides a clearer definition as to when a ramp should be used and when an exterior lift is required (due to height and space issues). As the first biomechanical study on residential access in snow and ice conditions, the project outcomes will be a basis for further work on ramp surfaces.

It is not surprising that quantitative mobility research has not been performed in a winter environment. Biomechanical laboratories are typically not setup to provide controlled snow and ice conditions. As well, typical video motion analysis systems are encumbered by winter clothing and reflections off snow and ice. The lack of available facilities and higher research costs (i.e., to setup and maintain controlled snow/ice and provide a safe testing environment) has limited the potential to answer critical questions for stakeholders in the accessibility domain.

Figure 2: CSTT climate chamber.

This study combines new partnerships, validated research methodologies, and consumer involvement to successfully evaluate how humans interact with external residential structures in winter. We worked with the National Research Council's Centre for Surface Transportation Technology (CSTT - http://www.nrc-cnrc.gc.ca/institutes/cstt_e.html) to perform analyses within an established environmentally-controlled research facility. CSTT's Climatic Engineering Division typically tests vehicles and equipment under a wide variety of climatic conditions and provides problem-solving support (cold-starting, defrosting, de-icing, snow ingestion, snow and ice accumulation, etc.). Combining CSTT's experience with controlled climates and the clinical and biomechanical expertise of the research team provided a unique research capacity for evaluating how winter affects residential accessibility and safe mobility.

7.1. Scope

The outcomes from this study are directly applicable to people with disabilities that use manual wheelchairs. Since the experimental protocol used a full-scale, controlled environment and involved self-propelling manual wheelchair users, the results are directly applicable to the target population. Results for ramp slopes that were too steep for viable independent navigation will be of interest to people who use manual wheelchairs with assistance (someone pushing chair) since similar navigation problems may exist. The experimental protocol from this study will be useful for future investigations with assisted propulsion and motorized wheelchair users. With the inclusion of a suspended safety harness, the research methodology will also be applicable to studies involving the elderly and people who use ambulatory assistive devices. Designers and building code writers will use the project results to better define appropriate ramp specifications in snow and snow-ice regions. Occupational therapists will benefit from a better understanding of biomechanical strategies for wheelchair navigation in winter conditions.

7.2. Objectives

- Define biomechanical strategies for safely ascending and descending ramps with snow and snow-ice coverage using a wheelchair
- Identify ramp slopes with snow and snow-ice coverage that are difficult or impossible to navigate
- Obtain information on wheelchair user perceptions regarding ramp use in winter

8. Methods

This study involved evaluating biomechanical performance and consumer feedback for a sample of manual wheelchair users as they propelled their wheelchairs up and down an exterior ramp. Packed snow and snow-ice-grit surfaces were prepared over 1:10, 1:12, and 1:16 grade inclines. This section describes the facilities, equipment, and protocols used to achieve these objectives.

8.1. Ramp Design

A portable ramp was designed based on the following criteria:

- 20 ft long ramp section with a landing
- Easily set up at the off-site facility
- Adjustable to slopes of 1:10, 1:12 and 1:16 with potential to accommodate 1:20 and 1:8
- Appropriate handrails, curb, surface, material, and load strength
- Incorporate a safety tether system to prevent uncontrolled sliding

Following a review of custom designs and commercial ramp systems, a prefabricated commercially available product was selected as the basis for the study ramp (Modular Ramp System by Add-a-Ramp, www.add-a-ramp.com). This modular ramp consisted of sections of moulded automotive grade fibreglass with moulded ribs on the underside for stiffness and a moulded-in skid resistant surface similar to surfaces used on diving boards. For this application, the components consisted of 3-6’ and 1-3’×44” wide sections, 5’square landing section, cross brace adjustable height leg supports, and adjustable height dual handrail system. In addition to the product’s modularity, this ramp could be disassembled and set up in a new location without cutting or drilling. Other beneficial features include the non-reflective ramp material, clear width between handrails of 44 inches, ramp segments with a built in 2 inch curb, all handrails 1.5 inches in diameter, and the lower handrail is continuously height adjustable.

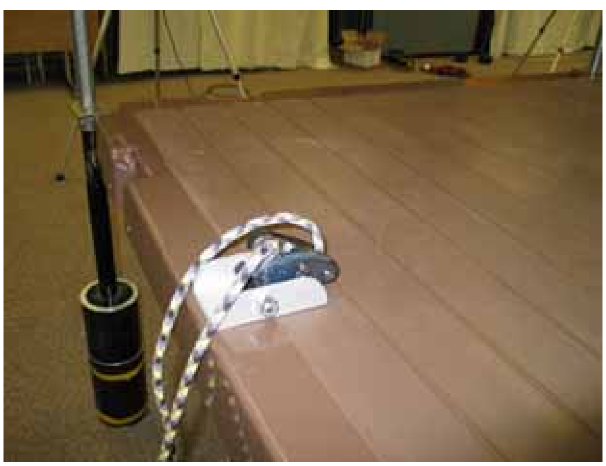
The Add-a-Ramp configuration also allowed for variation in the ramp slope; however, the adjustment method was too time consuming and limited in range for this study. A method to quickly change the slope during data collection was devised. After the ramp was levelled at the location using preset leg lengths, custom-made spacers were added to the footings to attain the desired slope (Figure 3). The spacers were constructed from 5 inch inner diameter steel pipe, wall thickness 0.25 inches. Fitted plates of machined aluminum were added to the top and bottom of the spacers. The top plate provide an inset to secure the original ramp footing and the bottom plate provided a surface to add felt to facilitate moving the ramp on smooth surfaces. Additional aluminum channels were affixed to the sides of the ramp to facilitate raising and lowering the ramp and to give additional strength and rigidity. A hydraulic lift was used to raise the platform, thereby increasing the ramp angle, while the spacers were changed.

The transitional area onto the ramp was also modified. The ramp starting area was lengthened to 30 inches to provide a more gradual approach and hinged to accommodate different slopes. On site, an additional 4’×8’ transitional area was added so that subjects would be starting from level ground.

Handrails were set to the maximum height of 38 inches. The second lower handrail was not installed since the railing would have potentially blocked markers from the cameras view.

A self-braking belay descender device (GriGri Belay Device by Petzl, www.petzl.com) and mounting climbing rope (Mammut Flash 10.5 mm Dry Rope, www.mammut.ch) were the basis for the safety tether system. Additional strapping was affixed to the client’s wheelchairs at the front and rear to provide secure attachment points for the safety rope. A carabineer clip secured the wheelchair strapping to the safety rope. Since the tether was attached to the wheelchair, a lap belt was fitted to each subject and their wheelchair to keep the subject in their wheelchair in the event that the safety line engaged.

The full ramp assembly is shown in Figure 3.



(b)

Figure 3: Ramp showing: a) self-braking belay descender device and spacers, b) full ramp assembly on-site.

Table 1: Portable Ramp Specifications.

Feature	Recommended Value	Rationale/Considerations	Final Specification
Adjustable slope	1:8 7.13° 1:10 5.71° 1:12 4.76° 1:16 3.58° 1:20 2.86°	▪ 1:10, 1:12, 1:16 only used for this research protocol; other slopes incorporated for future research ▪ 1:12 max. generally recommended [22]	1:10, 1:12, 1:16, and 1:8 with potential for 1:20.
Height	0" – 30"		4-34"
Length	20 ft. (2 - 10 foot sections) + platform	Sufficient length to accommodate all grades to a typical platform height	21 ft (3- 6 foot, 1- 3' sections) + platform
Width	36" (minimum)	DPCR 920 mm or 36" min Consider 48" for assistant (walking beside) more room for turning on the ramp; most prefab ramps are 36"	44"
Platform	65.75 × width (built) 5' × 5' (prefab)	▪ Sufficient room for wheelchair users to safely turn around ▪ Standard: Min. 1670 mm long × width of ramp for change in direction [22][22] ▪ 65.75 × 35.43 inches ▪ 5 ft 5.75 inches ▪ Prefab options 4'×4' and 5'×5' ▪ DPCR length 1500 mm or 59" min	5'×5'
Handrails – width		Min. width between handrails 900 mm (35.43") [22]	44"
Handrails – shape and diameter	Circular Outer Diameter (OD) 30-40 mm	▪ Must be continuously graspable along their entire length and have circular cross section OD 30-40 mm or non-circular shape perimeter 100-155 mm and largest cross section of 57 mm [22] ▪ At least 40 mm clearance to wall [22]	Circular OD 38 mm
Handrails - height	31"-38"	▪ 865mm - 965 mm (34.06"-37.99") [22] ▪ Original project spec. 31-36" adjusted but not adjusted for this protocol. ▪ 34-36" DPCR	Upper rail fixed 38"; Lower rail adjustable
Handrail Termination and Extension	300 mm beyond bottom of ramp	▪ Will not obstruct pedestrian travel or create a hazard [22] ▪ Extend at least 300 mm beyond bottom of ramp [22]	300 mm beyond bottom of ramp

Handrail - construction		▪ Withstand concentrated load at least 0.9 kN at any point in any direction [22] and uniform load of 0.7 kN/m applied in any direction ▪ Non reflective; minimal obstruction of camera view; single rail (no separate guard and rail)	Designed to support specified loads [22]. Non-reflective (Handrails painted black); minimal obstruction of camera view; lower rail removable
Side guards	omitted	▪ Guard on both sides 1070 mm from the top of guard to top of ramp surface [22] ▪ No member attachment or opening between 140 mm and 900 mm above ramp surface being protected by guard will facilitate climbing [22] ▪ Side guards would interfere with data collection; the safety tether provided a controlled supervised environment.	No side guards
Curb		▪ Standard 50 mm high where guard is not solid [22] (approx. 2") ▪ DPCR recommends 75 mm or 3" ▪ Also called "wheel guide or side edge; min. 2 inches high	Moulded 2" curb
Safety Tether		To prevent rapid decent and slipping on ascent	Self-braking belay descender device and rope tethered to wheelchair prevent rapid decent and slipping on ascent
Ramp – materials and construction		Aluminum framing; load = 2 people + device + snow = 500 lbs	Moulded composite with reinforced aluminum channel sides Original ramp designed to support a live load of 100 lbs/ft^2 and concentrated load of 300 lbs. [23]
Ramp Surface Material		Consider composite platforms, plywood, decking material, non-skid covering	Composite; moulded skid resistant surface
Handrail Height Adjustment		Needs to be adjusted quickly and fastened securely	Handrail fastened securely; adjustments made with Allen key
Slope Adjustment		Ramp moved manually, consider assist with portable lift; consider pneumatic lift bag	Small jack and hydraulic lift assist in moving ramp

Portability		Partially disassemble, transport, reassemble; consider handles for lifting, max weight of component parts, quick connect main ramp sections attach to ramp support arm; hinge ramp connection at platform	Criteria met
Ramp supports		Structural supports along the ramp at joints and landings; facilitate height adjustment	Height adjustable supports located at joints; further adjustment provided through addition fabricated supports

8.2. Preliminary Testing

A preliminary testing session was conducted at The Ottawa Hospital Rehabilitation Centre to evaluate ramp setup, ramp angle change procedures, test camera placement, and conduct test data collection. A 5.8 metre wide area was measured within the test space to represent the Centre for Surface Transportation Technology (CSTT) laboratory. Ramp setup time, including levelling, was approximately 90 minutes. After practicing ramp angle changes, the time to perform these changes was less than 10 minutes. Two people were required to efficiently change the ramp angle. Optimizing the ramp angle change time was essential for completing all subject testing within the available Climate Laboratory time.

The Vicon motion capture system [21] was used to record 3D upper limb, head, and trunk motion during ramp navigation. As shown in Figure 4, ten Vicon MX-3+ cameras were positioned with four cameras along the left and right side of the ramp and one camera at the ramp's front and back. Camera positioning is critical to achieve accurate 3D limb marker positions since having more cameras see a marker during locomotion reduces the chance of obstructions masking the marker (i.e., railings, hands/arms) and improves system accuracy. Due to the ramp's length, the cameras were oriented such that the markers at the beginning and end of the ramp were visible by three cameras. In the mid-ramp region, markers were visible by four cameras.

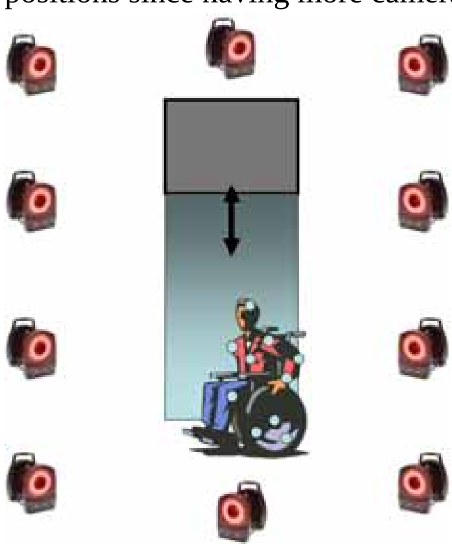


Figure 4: Vicon camera positions.

The Vicon motion capture cameras use synchronized strobe lights to illuminate reflective markers on the subject. Since the snow/ice data collection environment has a larger potential of producing reflections, resulting in erroneous marker identification, cameras must be positioned to minimize or eliminate these reflections. As shown in Figure 4, these camera positions were setup on tripods. While camera angles and spacing were successfully configured for optimal camera view coverage and such that the strobe lights were off-angle from other cameras, the tripod heights were insufficient for the entire ramp length. In contrast to level ground motion analysis, the cameras were required to be at least 2.75 m off the ground to have other cameras at the top, or out, of the camera view (i.e., so that cameras were not confused with markers and important areas were not masked out in the analysis software).

Figure **5**: Preliminary test environment.

Reflection errors from the ramp supports and railing were identified during preliminary testing. These reflections were temporarily eliminated by covering the reflective surfaces. For CSTT testing, the support bars and railing were painted flat black to permanently eliminate these errors.

Data collection was verified by performing five successful Vicon calibration trials and collecting a series of sample trials. Reflective markers were attached to a wheelchair and a project team member. The wheelchair was propelled up and down the ramp to verify marker capture capability and camera view positions. The wheelchair was also stopped at the beginning, middle, and top of the ramp to verify that the system accommodated all subjects seated height and reach.

Once camera height factors in the preliminary test environment were considered, data collection trials were successful. Following the data collection verification, the safety tether system was verified by engaging the safety system during ramp descent. The safety system was also verified to ensure that the tether would not impede wheelchair propulsion and that the system could keep up with rapid ramp descent speeds. Following the safety evaluation, the system was ready for implementation in the CSTT facility.

Figure 6: Subject with reflective markers.

8.3. Biomechanical Marker Set

For this project's kinematic data collection requirements, a marker set was used to identify both wheelchair and subject parameters (Figure 6, Appendix A). The wheelchair seat plane was identified using four markers, and acted as both a measure of wheelchair orientation and a reference for trunk angle. The pelvis is typically the reference segment for upper trunk angle; however, marker obstruction from the wheelchair, arms, and shoulders precluded use of this segment with video motion analysis. Since all subjects wore a waist belt for safety purposes and wheelchair users have minimal pelvic movement relative to the wheelchair seat, using the seat plane as a representative segment for upper trunk kinematics is reasonable. Three markers were attached to each wheel to calculate wheel kinematics. Multiple markers on the upper torso/back, upper arms, lower arms, and head were used to identify these body segments in three dimensions. A standardized origin position was set on the ramp for the motion analysis system so that the wheelchair and all segments could be referenced to the ramp dimensions.

8.4. National Research Council, Centre for Surface Transportation Technology: Climatic Engineering and Testing Division

The CSTT Climate Engineering Facility (Climate Lab) is Canada's largest climatic chamber. The facility can produce temperatures ranging from -51°C to +55°C and includes a full suite of instrumentation and 190 channels for data recording to track performance under conditions of snow, rain, freezing rain, ice, and fog – and even a combination of those conditions, changing where needed over a period of time to simulate changing weather. The chamber measures 30 metres in length, 6 metres in width, and 6 metres in height.

As the first group to perform quantitative motion analysis in the Climate Lab, various adaptations were necessary. Space in the control room, a room adjacent to the chamber with all climate control and monitoring equipment, was made available for the Vicon computer, for preparing test subjects, and to provide a warm space for subjects to wait between trials.

8.5. Setup

To provide maximum field of view and to allow Vicon camera positioning at a sufficient height, magnetic camera platforms were produced that could be attached to the Chamber’s metal walls. Camera mounts were attached to the platforms to enable camera rotation and locking in the appropriate orientation (Figure 7).

One day was required for equipment transfer, ramp and camera setup, optimizing camera positioning, cabling, and onsite data quality evaluation. A 4’×8’ sheet of ¾” plywood was mounted on a wooden frame and placed at the beginning of the ramp to provide a consistent starting platform.

Figure 7: Camera mount.

Following the setup process, the camera mount positions were marked and all cameras and electronics were removed from the Chamber. The Chamber temperature was lowered to -22°C and left to achieve thorough cold penetration in the concrete floor. Two days later, snow was made in the chamber to provide approximately 4 cm of cover on the ramp and sufficient snow on the ground to create and maintain the packed snow test scenario (Figure 8).

On the morning of testing, the project team remounted the electronics and Vicon cameras before conducting another series of calibration and data collection tests to verify data quality. The snow was manually packed on to the ramp by foot, thereby producing a more realistic winter scenario. The packed snow was approximately 3 cm deep.

Figure **8**: CSTT ramp setup, before and after snow production.

8.6. Data Collection

All subjects were greeted at the CSTT reception and escorted to the Climate Chamber. After ensuring that the subjects understood the project protocol, each subject completed a consent form and a questionnaire about their experiences with wheelchair propulsion in winter (Appendix A). An occupational therapist and rehabilitation engineer evaluated each subject's wheelchair to ensure that the device was in good working order (i.e., appropriate for safe ramp navigation under the test conditions).

After adhering reflective markers onto the subject's wheelchair, the subjects donned winter clothing. Pro Wrap (a light polyurethane pretaping foam underwrap used to protect skin from tape) was wrapped around the upper arms and/or forearms to help minimize clothing motion over the limbs. Reflective markers were placed on the segments and measurements were made on the limbs and wheelchair (Appendix A). A belt strap was attached to the wheelchair and the subject to ensure that they did not leave the wheelchair if the safety tether was engaged.

Subjects were accompanied into the Climate Chamber by the Occupational Therapist. Two research assistants were also in the chamber to start a digital video camera, which recorded all trials, and to work the safety tether. While all subjects were offered the opportunity to practice on the ramp, all subject elected to proceed directly to the test trials (Figure 9).

A static trial was recorded at the start of each subject's test day to orient marker positions to anatomical segments in the Vicon Nexus software. Due to testing time limitations and physical demands of the snow-navigation task, three trials were recorded for each subject as they ascended and descended the ramp. The tether was secured to the front of the wheelchair during ascent trials and to the rear of the wheelchair during descent. All trials were sampled at 100 Hz. The two research team members repaired any ruts in the packed snow between each trial.

Subjects were scheduled in groups of 2–4 people. All subjects in the group completed their three trials at one ramp angle before the angle was changed. Trials were performed at 1:10, 1:12, and 1:16 grades. Four hours were required to test a group of four subjects in the snow condition. If the subject was unable to ascend the ramp from the bottom, they were repositioned and started approximately ¼ up the ramp.

Figure **9**: Subject with tether on chair front (left) and subject in static position (right).

Following the last snow trials, CSTT staff lowered the Chamber temperature to -20°C and then manually applied cold water to the packed snow surface of the ramp. This produced an ice covering consistent with heavy freezing rain (approx 1.5-2.0 cm thick). Gravel grit was sprinkled onto the ice surface. This snow-ice-grit surface is consistent with prepared exterior ramps and inclines in winter. Since the ice thickness covered the safety boarder on the sides of the ramp, 2”×6” pine boards were attached to the ramp posts to ensure that the wheelchair would not slide off the side of the ramp (Figure 10,Figure 11).

Figure **10**: Ramp with snow-ice-grit cover.

Video analysis was used to calculate time to ascend and descend the ramp, count the number of times the wheelchair became stuck, and graded the severity of these obstructions. Becoming stuck was identified by instances where forward progression of the wheelchair was stopped and the subject required an intervention to reinitiate motion (i.e., this did not include cases where the subject stopped to reposition hands, etc. on the highest ramp grade). Mild obstructions were short time delay events that did not require external assistance. Moderate obstructions were of longer duration but did not require external assistance. Severe obstructions were of long time duration and often required external assistance to reinitiate motion.

Video analysis was also used to identify the strategy used to ascend the ramp. Separate obstruction and strategy analyses were performed for the bottom, middle, and top of the ramp.

Figure **11**: Ice condition testing.

9. Results / Discussion

9.1. Subjects

Eleven subjects were successfully recruited for this study, seven male (average age: 46.86) and four female (average age: 41.25) (Table 2). Ten subjects completed the snow conditions and ten subjects completed the snow-ice-grit trials. The average number of years of wheelchair use was 23.5 years (SD=18.2). All but one subject lived in a house; one subject lived in an apartment.

Except for Subjects #6 and #7, all participants used very lightweight manual wheelchairs with their centre of gravity close to the rear axle (minimal weight on the front wheels). The other two wheelchairs were set up quite differently, with a more equal weight distribution on the frame but no possibility to perform wheelies (i.e., front wheels off the ground).

Subjects #3 and #11 had pneumatic 24 x 1 3/8" threaded rear tires, while all the others had Hi-Pressure (HP) thinner models of different radius. All front tires were constructed of solid composite ranging from 7/8" (Poly and Blades) to 1 ¼" (Soft Roll) in terms of thickness, with two equipped with suspension forks (Frog Legs ™). The activity level rating of Low-Moderate-Active was assigned by the Occupational Therapist during the initial interview and based on participant's physical and functional abilities.

Table 2: Subject and wheelchair characteristics.

Subject #	Age	Gender	Activity Level	Wheelchair	Tires
1	36	M	Moderate	Tilite TR	25 Marathon Plus HP + 3 Blade
2	47	F	High	Tilite Zra	24 Kenda HP + 3 Blade
3	45	M	Moderate	Tilite Zra	24 Pneumatic + 5 Poly
4	43	M	High	Tilite TR	24 Kenda HP + 3 Frog legs
5	49	F	Moderate	Tilite TR	24 Primo HP + 4 Frog legs
6	58	M	Moderate	Invacare X4	24 Primo HP + 5 Soft Roll
7	53	M	Low	Q2 Long frame	24 Pneumatic + 6 Poly
8	26	F	High	Tilite Zra	24 Marathon Plus HP + 4 Poly
9	50	M	Low	Tilite Zra	25 Primo HP + 4 Poly
10	43	F	High	RGK MAX	24 Kenda HP + 3 Blade
11	43	M	High	Invacare A4	24 Pneumatic + 5 Poly

The available time in the CSTT facility (1 setup day, 2 days of snow trials, 2 days of snow-ice trials, and 1 morning to clear-out) created scheduling issues with most of the potential subject population.

For future studies that use the CSTT facility, and require a larger sample size, a larger budget is required to reserve more testing time in the Climate Chamber. The testing must also proceed on weekends and evenings to accommodate wheelchair users with full time jobs (i.e., although this would potentially increase project costs due to overtime payments at the NRC facility). Focussing on one winter condition would also be beneficial since subjects would not have to return for additional testing (i.e., a person may volunteer to participate if they only need to take a half-day off work).

9.2. Questionnaire – Experiences with Exterior Ramps

The subject's rating of overall capacity to safely ascend and descend ramps by season is listed in Table 3. Sixty-four percent of subjects had a home ramp and 27% had a home lift. In terms of the subject's perceived ability to safely ascend ramps, results were similar for spring, summer, and fall. 55 to 64% of subjects considered ramp navigation in these seasons to be the same as level ground and 18% considered the ramp navigation to be "very difficult but I can ascend all ramps". Winter results showed increased difficulty with most subjects (55%) rating ramp ascent as "more difficult than level ground" and 27% rating "very difficult, I cannot ascend some ramps".

Ramp descent results were similar to the ascent results, but with more subjects considering the task easier to perform. 73% considered ramp descent to be the 'same as level ground" in summer, spring, and fall; with 64% having more difficulty than level ground in winter.

Seventy percent of subjects considered ramp ascent to be more challenging than descent during winter. The result showing 64% of subjects being concerned with ramp descent, and 18% unable to independently descend all ramps in winter, should be recognized since ramp descent issues are not limited to physical strength and balance, as commonly considered for ascent.

Most subjects reported never requiring assistance ascending ramps (55–64%) or descending ramps (73%) during spring, summer, or fall. However, almost half the subjects sometimes required assistance for ramp ascent during winter, with 18% sometimes requiring assistance with winter ramp descent (Table 4). Only one subject reported an injury while navigating a ramp in winter, which did not result in a clinic visit.

Table **3**: Rating of overall capacity to safely ascend and descend ramps by season (percentage of total number of subjects).

Ramp	**Season**	**Same as level ground**	**More difficult than level ground**	**Very difficult, but I can ascend/descend all ramps**	**Very difficult, I cannot ascend/descend some ramps**	**Safe ramp ascent/descent is rarely possible**
Ascent	Spring	54.5	27.3	18.2		
	Summer	63.6	18.2	18.2		
	Fall	54.5	27.3	18.2		
	Winter	9.1	54.5	9.1	27.3	
Descent	Spring	72.7	9.1	18.2		
	Summer	72.7	9.1	18.2		
	Fall	72.7	9.1	18.2		
	Winter	36.4	27.3	18.2	18.2	

Table **4**: Incidence of assistance when ascending and descending ramps by season (percentage of total number of subjects).

Ramp	Season	Never	Rarely	Sometimes	Often	Always
Ascent	Spring	63.6	36.4			
	Summer	63.6	36.4			
	Fall	54.5	36.4			
	Winter	27.3	18.2	45.5		
Descent	Spring	72.7	18.2			
	Summer	72.7	18.2			
	Fall	72.7	18.2			
	Winter	36.4	36.4	18.2		

Most subjects (80%) used handrails as a strategy for winter ramp navigation and 50% installed a residential ramp with a gentle slope. The remaining strategies were minimally used: covered ramp (1 subject), lift (1 subject), heated ramp (1 subject), and slip resistant surface (2 subjects).

One open-field question asked subjects to list the five most challenging barriers for safe wheelchair mobility during winter. All respondents included snow and ice conditions as general barriers. The lack of handrails, or slippery handrails, were reported as a barrier by 60% of respondents. The lack of handrails on sidewalks and similar inclined surfaces was considered a major barrier, if these surfaces are not adequately cleared of snow and/or ice. Approximately 40% of subjects considered poor grip on the wheelchair rims/wheels to be a barrier for safe mobility during winter. This scenario is caused by wet and/or icing on the wheels and rims and inadequate gloves for winter wheelchair propulsion (i.e., gloves become slippery as they get wet and do not provide an adequate moisture barrier for winter use).

9.3. Questionnaire – Subject Ratings of Ramp Navigation Conditions

As shown in Figure 12 and Table 5, a general trend existed with “ascending the steepest slope in the snow condition” being the most difficult and “descending the lowest slope in the snow-ice-grit condition” considered the easiest.

Table **5**: Cumulative ramp condition ratings as a percentage of the number of subjects.

	Very Easy	Easy	Moderate	Difficult	Very Difficult
Ascent Snow - 1:10				50%	50%
Ascent Snow - 1:12			40%	40%	20%
Ascent Snow - 1:16		20%	40%	20%	20%
Ascent Ice - 1:10		44%	33%	11%	11%
Ascent Ice - 1:12	11%	56%	33%		
Ascent Ice - 1:16	22%	78%			
Descent Snow - 1:10		10%	40%	40%	10%
Descent Snow - 1:12		40%	40%	20%	
Descent Snow - 1:16	10%	60%	10%	20%	
Descent Ice - 1:10	22%	44%	22%	11%	
Descent Ice - 1:12	44%	44%	11%		
Descent Ice - 1:16	78%	22%			

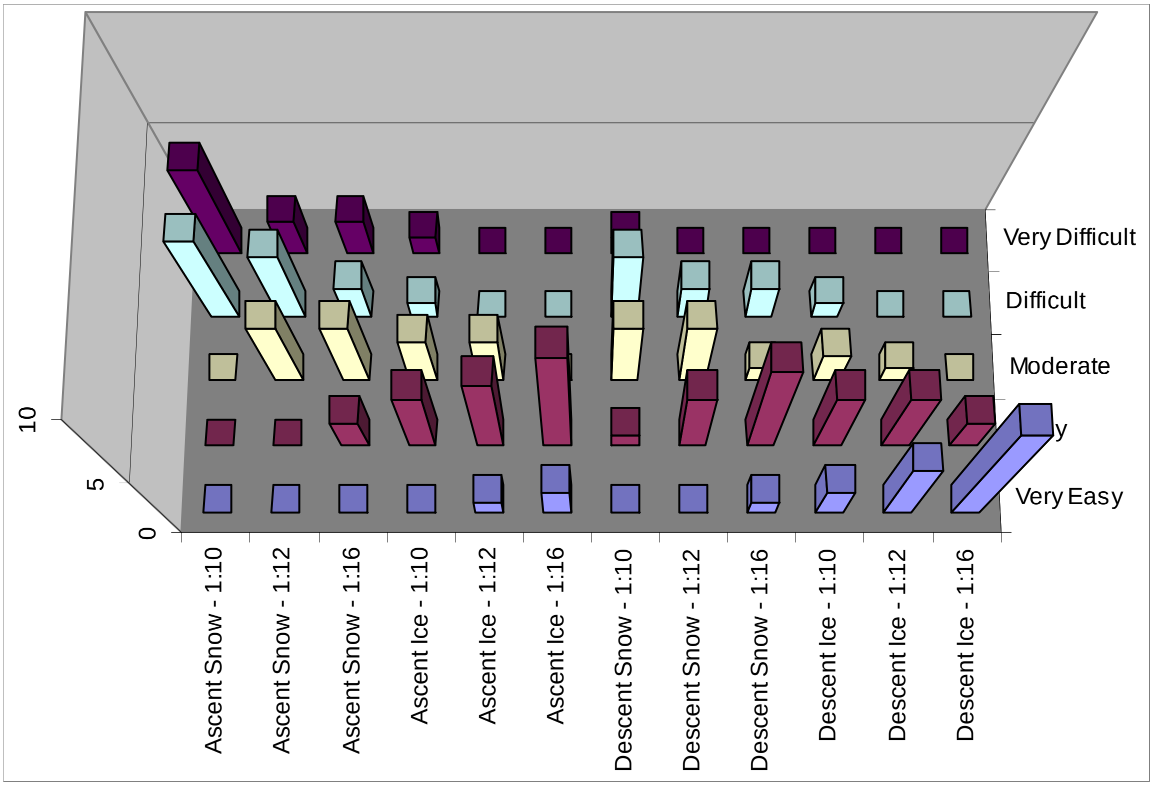


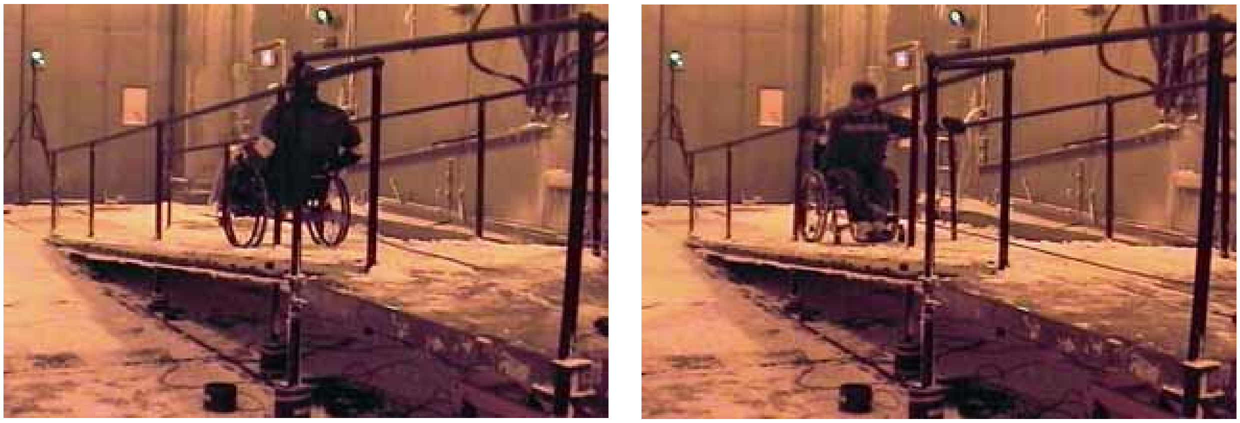
Figure **12**: Cumulative subject ratings of the six ramp conditions.

9.4. Condition Analysis

9.4.1. Snow Summary

The snow cover scenario was more difficult to navigate than the snow-ice-grit cover. One subject was unable to ascend the ramp at the 1:10 grade and many subjects required assistance when the wheelchair became stuck in the snow. Four subjects were unable to perform the transition from level ground to ramp and therefore started ¼ of the way up the ramp.

While the snow was packed, the front wheels typically dug into the snow layer, effectively braking forward wheelchair progression. A wheelchair manoeuvre was required to free the front wheels; such as, rocking back on the rear wheels (wheelie), side-to-side shifting, vertical pull-up using the handrails, or simultaneous tilting and rotating the wheelchair. Subjects who required assistance typically were unable to free the front wheels and became stuck midway on the ramp, mainly on the 1:10 grade. Once the front wheels were back on level, packed snow, the subjects were able to continue ascending the ramp. All subjects were able to descend the ramp in snow conditions unassisted (Figure 13).



(a) **(b)**

Figure **13**: Ramp navigation: a) descent using two wheels/wheelie, b) ascent using hand rails.

One subject ascended the ramp by rolling backwards, by pushing on the handrails, thereby avoiding problems with the smaller front caster wheels digging into the snow. Wheelchair users should consider this approach when two appropriately installed handrails are available.

Methodologically, maintaining packed snow conditions was difficult due to the front wheels digging into the snow. Even though the snow was manually repacked by tamping down the snow after each trial, the lowest ramp section was "softer" than the middle and top sections following the first subject's trials. This is consistent with questionnaire feedback from subjects on their past experiences with wheelchair use in winter where transitioning from level ground to an incline is typically difficult due to snow build-up at the bottom of exterior ramps. For this study, the transition issue may more correctly be stated as "softer snow conditions" at the bottom of the ramp, where the front wheels more easily sink into the snow and stop forward progression as they plow the snow into an immovable obstacle. This is in contrast to harder-packed snow conditions that cause less of an impediment to forward progression.

As shown in Figure 14, differences were found between strategies for the bottom, middle, and top sections of the ramp. Therefore, these sections were analyzed separately.

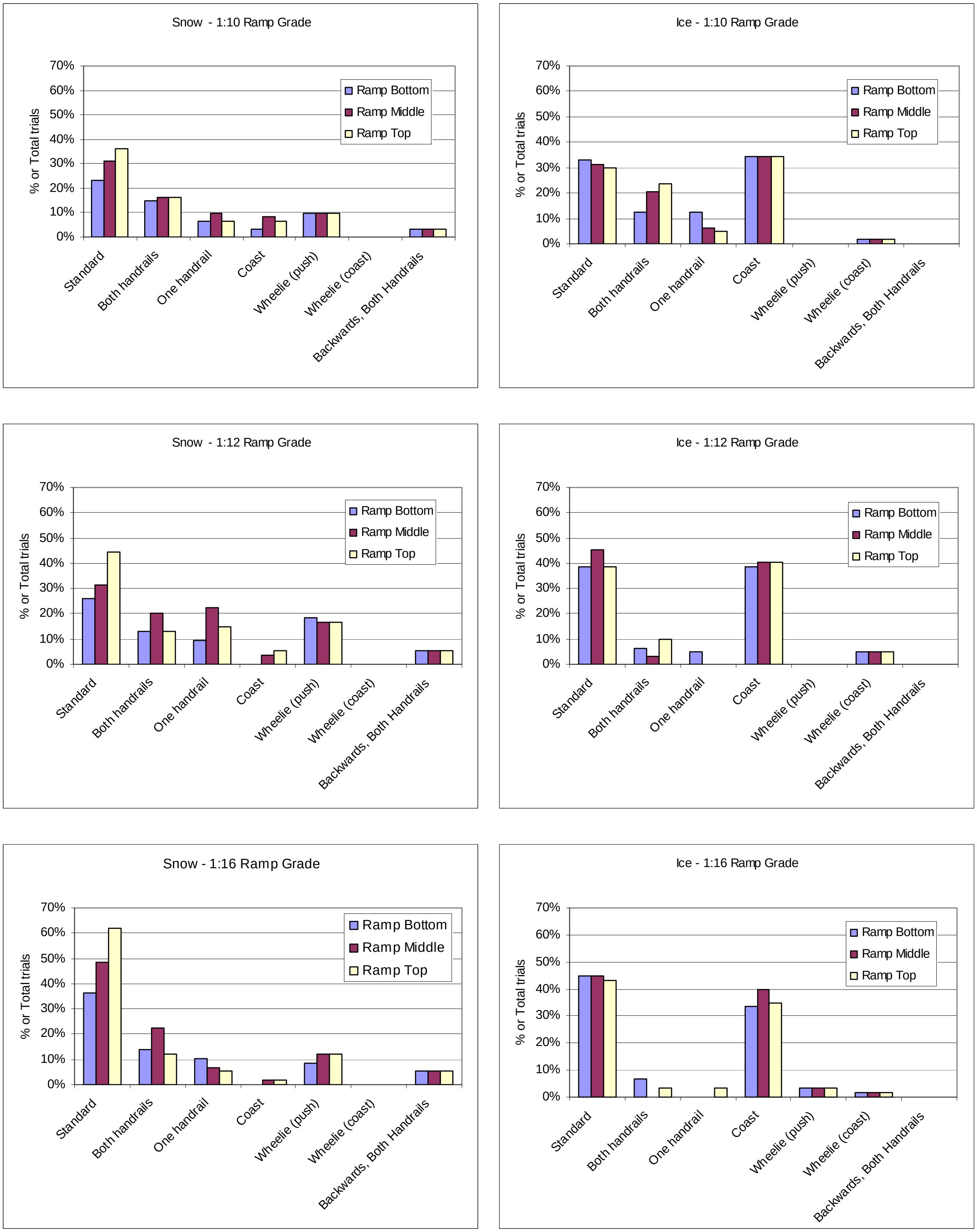


Figure 14: Strategies for ramp navigation (percent of number of trials).

Seven strategies were used for ramp navigation: standard propulsion (i.e., pushing on wheel rims), use both handrails (pull up on ascent or slow down chair on descent), one hand on handrail and one on opposite wheel, coast (i.e., wheelchair rolls down ramp without user propelling chair), wheelie with user push on rims, wheelie while coasting down ramp, and backwards ramp ascent using both handrails. Typically, a combination of strategies were used; for example, two handrail to initiate movement, standard propulsion until wheelchair progression is halted due to front wheel obstruction, one hand rail to clear front wheels, and a combination of standard and two railing propulsion for the top ramp section.

As shown in Figure 15-Figure 17, standard propulsion was used for most trials. Subjects were predominately unable to coast down the ramp for snow conditions, while approximately 75% of subjects were able to coast down the ramp in the ice-grit condition. This was expected since the ice condition provided a relatively smooth surface that did not affect wheel rotation and did not allow front wheel obstruction as with snow conditions.

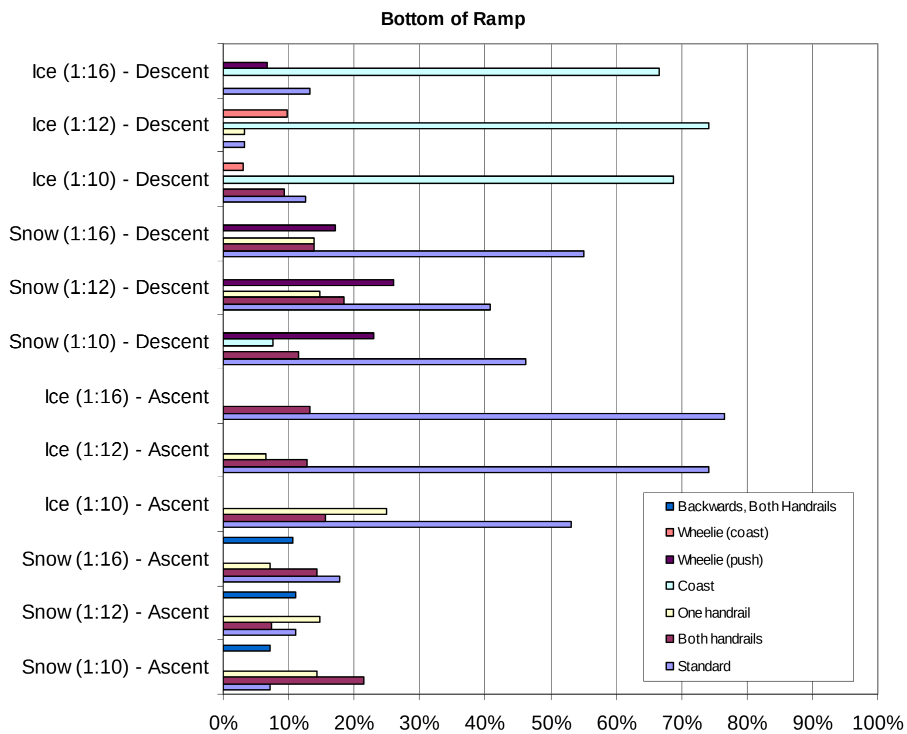


Figure **15**: Bottom section strategy as a percentage of the number of trials per condition.

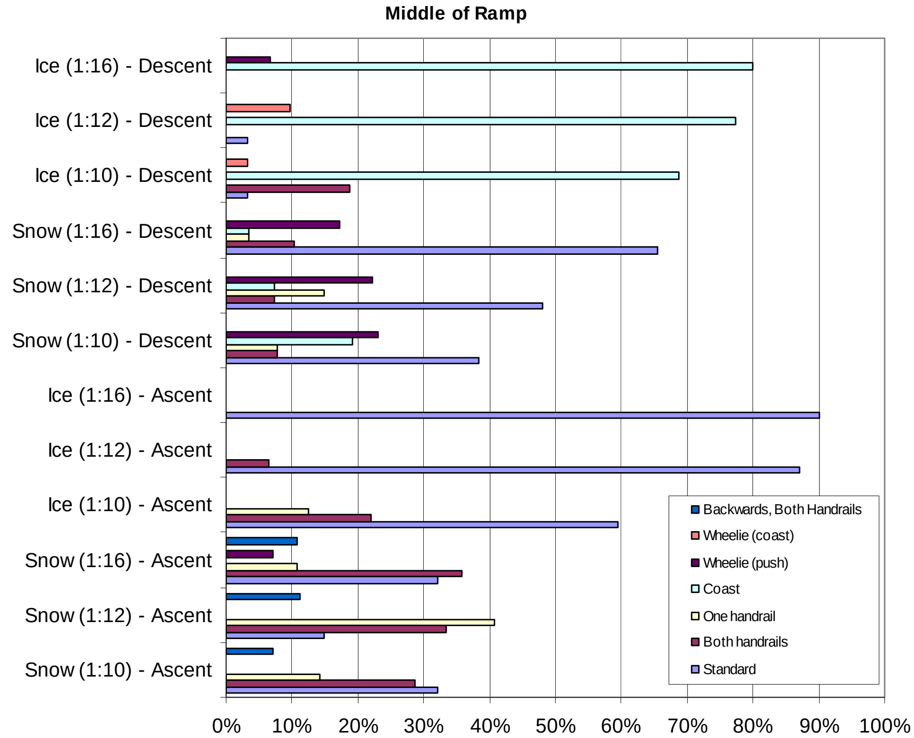


Figure **16**: Middle section strategy as a percentage of the number of trials per condition.

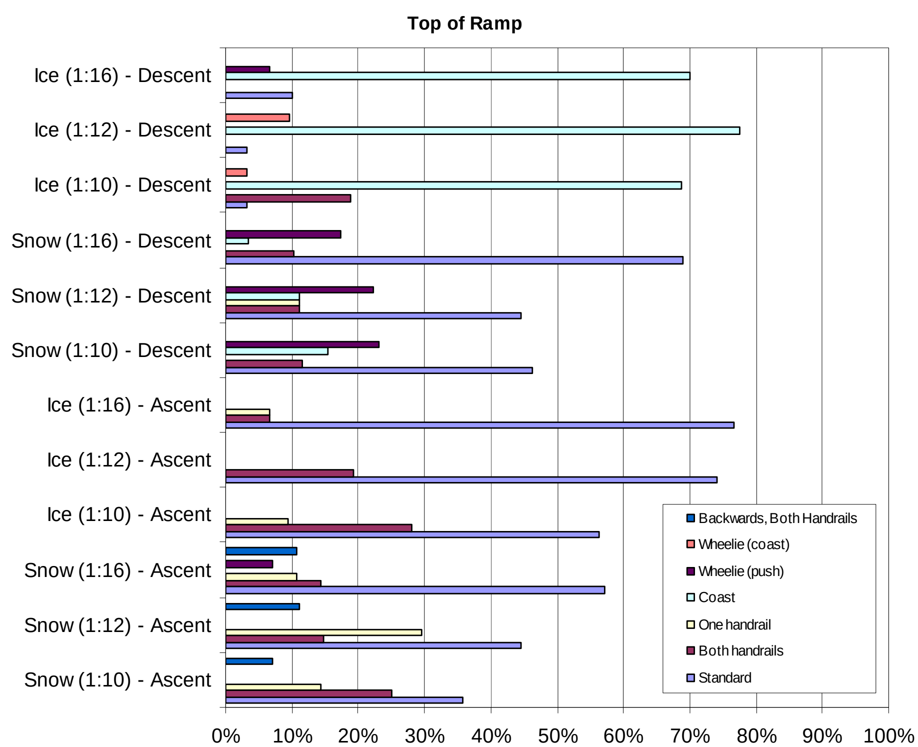


Figure **17**: Top section strategy as a percentage of the number of trials per condition.

During the first test day, the subjects benefited from firmer packed snow at the transitional section from level ground to the lower ramp section. The very active wheelchair users, subjects 1, 2 and 4, were able to ascend the entire ramp under these snow conditions.

One subject on the first test day (Subject #3) was unable to ascend the entire ramp, and therefore started at ¼ of the distance up the ramp. Even with this change, this person was only able to ascend the 1:10 ramp grade once without assistance (one trial successful, one failure, one with assistance at the top section). At 1:12, Subject #3 was able to ascend, starting at the ¼ point, but with difficulty at the top section. Then 1:16 grade was successfully navigated since Subject #3 was able to raise the front wheels while pushing (wheelie-push strategy).

On day two, a very active subject (6) was the last to perform the snow trials. Since the previous trials had softened the transition area at the bottom of the ramp, Subject #6 started at the ¼ point. At the 1:10 grade, this person required assistance to start but was able to ascend using standard wheeling over the middle and top section. At 1:12 and 1:16, Subject #6 used the handrails to ascend the ramp, starting at the ¼ point, without assistance.

Of the subjects on day 2 (# 6–9), Subject #6 was the only person who was able to ascend the entire ramp. The first trial, using forward propulsion, was a failure. However, Subject #6 successfully completed all ramp ascent grades, under snow conditions, by rolling backwards and pulling on both handrails. This approach avoided the problems with the smaller front wheels digging into the snow when the torso rotated forward during propulsion. Only two obstructions were recorded over all backwards ascent trials (1 mild, 1 severe).

However, forward descent for Subject #6 resulted in severe problems at the ramp bottom section, with severe obstructions for seven descent trials and one mild obstruction. Many of these trials required external assistance to lift and move the front wheels so that the subject could move the wheelchair. Four descent trials also had problems in the middle section. As someone in the lower activity category, it was not surprising that Subject #6 had problems with both front wheels digging into the snow. Since this subject could not perform the wheelie action during descent, he was unable to removing the wheelchair from the obstructed situation and continue motion. The decent problems draw attention to the potential for the backward ramp ascent strategy as a viable model for snow conditions.

Subject #7, the lowest functional subject, was unable to ascend the ramp at the 1:10 grade. Subjects #8-9 started ¼ of the way up the ramp but still required external assistance to complete the bottom portion of the ramp ascent at 1:10. Difficulties were also experienced by these three subjects at the middle and especially at the top of the ramp. Subject #7 required external assistance to ascend the 1:12 grade, with severe problems ascending the top section, but was able to perform the 1:16 grade independently.

Table 6: Percentage of trials where wheelchair became stuck and severity of the obstruction.

	Bottom			
	Stuck	**Mild**	**Moderate**	**Severe**
Snow (1:10) - Ascent	39%	29%	7%	4%
Snow (1:12) - Ascent	30%	22%	4%	4%
Snow (1:16) - Ascent	29%	25%	4%	
Snow (1:10) - Descent	35%	27%		8%
Snow (1:12) - Descent	41%	19%	7%	15%
Snow (1:16) - Descent	24%	10%	7%	7%
Ice (1:10) - Ascent	3%	3%		
Ice (1:12) - Ascent	3%	3%		
Ice (1:16) - Ascent	3%	3%		
Ice (1:10) - Descent				
Ice (1:12) - Descent				
Ice (1:16) - Descent				
	Middle			
Snow (1:10) - Ascent	29%	11%	11%	7%
Snow (1:12) - Ascent	59%	30%	11%	19%
Snow (1:16) - Ascent	36%	14%	11%	11%
Snow (1:10) - Descent	27%	8%	19%	
Snow (1:12) - Descent	19%	15%		4%
Snow (1:16) - Descent	17%	10%	3%	3%
Ice (1:10) - Ascent	9%	9%		
Ice (1:12) - Ascent				
Ice (1:16) - Ascent				
Ice (1:10) - Descent				
Ice (1:12) - Descent				
Ice (1:16) - Descent				
	Top			
Snow (1:10) - Ascent	7%	4%		4%
Snow (1:12) - Ascent	11%	7%	4%	
Snow (1:16) - Ascent	14%	14%		
Snow (1:10) - Descent	8%	8%		
Snow (1:12) - Descent	4%	4%		
Snow (1:16) - Descent	7%	7%		
Ice (1:10) - Ascent	3%	3%		
Ice (1:12) - Ascent				
Ice (1:16) - Ascent	3%	3%		
Ice (1:10) - Descent				
Ice (1:12) - Descent				
Ice (1:16) - Descent				

For ramp descent, Subject #7 was able to descend the entire ramp for all ramp grades, with mild to severe difficulties navigating the bottom section. Handrails were used to assist with ramp descent, both to control speed and to extract the wheelchair when stuck. At 1:10 and 1:12, standard wheelchair propulsion was typically used for the top portion, with handrails being employed in the bottom portion where the packed snow was softer.

The strategy for pulling on one-handrail while pushing on the opposite wheelchair wheel was typically used for ramp ascent to dislodge front wheels that were stuck, although one subject used this approach for ramp ascent. This approach facilitated forward progression while offloading the front wheels. Pulling on both handrails was not as successful since the torso was forced to rotate forward to a greater degree than the one-handrail approach, thereby moving the body centre of gravity forward and increasing load on the front wheels. In most cases, this "two-railing pull" manoeuvre failed to dislodge the front wheels from the rut, often resulting in the back wheels being lifted as the chair rotates over the front wheels.

9.4.2. Ice Summary

Subjects considered the packed snow-ice-grit condition to be easier to navigate than the snow condition, mainly because the wheels did not pass through the ice and dig into the snow. While the wheels did periodically slip during ramp ascent and descent, the tether system was not required to maintain wheelchair control. The importance of adequate grit, or other friction enhancing substance, on exterior ramps after ice conditions cannot be discounted. Subjective feedback from some subjects indicated that many exterior ramps do not have sufficient grit on the surface, thereby creating a more difficult wheelchair navigation scenario than the research setup. Guidance for building maintenance policy on the amount of grit required for wheelchair navigation would be of benefit for safe navigation under these conditions. It was also observed that, over a short period, the grit became embedded in the ice, decreasing its effectiveness and thus required replenishing periodically over the day.

All subjects were able to ascend and descend the ice-grit ramp conditions without assistance, at all grades, and starting at the bottom or top of the ramp. Only seven mild stoppages were reported for ice-grit ramp ascent, although wheel slip did occur on the ice-grit surface that did not produce a stoppage in forward progression. No problems occurred for ramp descent.

For ice-grit conditions, pulling on two handrails was a successful approach since this strategy moved the propulsive force from the wheel rims to the ramp structure. This minimized the chances of wheel slip during standard propulsion (i.e., where larger forces are applied to the rim for 1:10 ascent, resulting in larger moments about the wheel, causing the propulsive force to be larger than the friction between the tire and the surface).

During ramp decent on ice-grit, most people coasted, and using their hands on the rims or railings to control speed and heading.

9.5. Speed

As shown in Table 7, the average speed ranged from 0.18 to 0.65 m/s, with larger values found for ramp descent. Since some of the less able subjects did not complete the 1:10 grade in snow conditions, but were able to complete the 1:12 trials, the average speed was slightly greater than the snow (1:12) trials (i.e., including slower wheelchair users in the 1:12 snow trials reduced the average speed across subjects).

Subjects took an average of 32.74s (s=20.31) seconds to ascend the 1:10 grade ramp in snow conditions, the longest time, and 26.35s (s=13.47) for the 1:10 ice condition (Table 8). The fastest time was for the 1:16 ramp descent on ice-grit (9.95s, s=5.04). Slower descent for the 1:10 ice-grit condition but may have been due to reduced confidence in the participant's ability to control the wheelchair at the steeper grade or more confidence after completing the 1:10 and 1:12 grades trials (i.e., learning effect).

Table 7: Average speed for ramp ascent and descent.

	Condition	Average (m/s)	Stdev	Average (m/s)	Stdev
Ascent	Snow (1:10)	0.21	0.08	0.20	0.07
	Snow (1:12)	0.18	0.08		
	Snow (1:16)	0.23	0.06		
	Ice (1:10)	0.25	0.11	0.38	0.20
	Ice (1:12)	0.38	0.19		
	Ice (1:16)	0.54	0.21		
Descent	Snow (1:10)	0.27	0.14	0.30	0.16
	Snow (1:12)	0.30	0.16		
	Snow (1:16)	0.32	0.18		
	Ice (1:10)	0.50	0.20	0.57	0.22
	Ice (1:12)	0.56	0.22		
	Ice (1:16)	0.65	0.24		

Table **8**: Time for ramp ascent and descent.

	Condition	Average (s)	Stdev	Average (s)	Stdev
Ascent	Snow (1:10)	32.74	20.31	29.35	12.91
	Snow (1:12)	30.86	9.24		
	Snow (1:16)	25.60	6.22		
	Ice (1:10)	26.35	13.47	19.84	12.53
	Ice (1:12)	19.19	12.89		
	Ice (1:16)	12.23	6.85		
Descent	Snow (1:10)	29.35	23.81	27.36	20.79
	Snow (1:12)	26.12	17.63		
	Snow (1:16)	26.69	22.59		
	Ice (1:10)	13.72	8.83	12.00	7.15
	Ice (1:12)	12.10	7.12		
	Ice (1:16)	9.95	5.04		

9.6. Propulsive Strokes

The number of propulsive strokes is an indicator of difficulty for ramp navigation since cases where the wheelchair becomes stuck, where the wheels slipped and where multiple short strokes are required, are reflected in the stroke count. As shown in Figure 18, while the mean values were similar across grades for snow ascent, the standard deviations and maximum values were progressively larger as the ramp angle increased. The ice-grit ascent trial stroke counts were 25-35% lower than the snow trials, although the average values for 1:10 grade were similar to snow. At 1:10, smaller, lower force, strokes were required to ascend the ramp without having the wheels slip on the ice. As well, wheel slip at 1:10 required extra propulsive strokes to complete the ascent task.

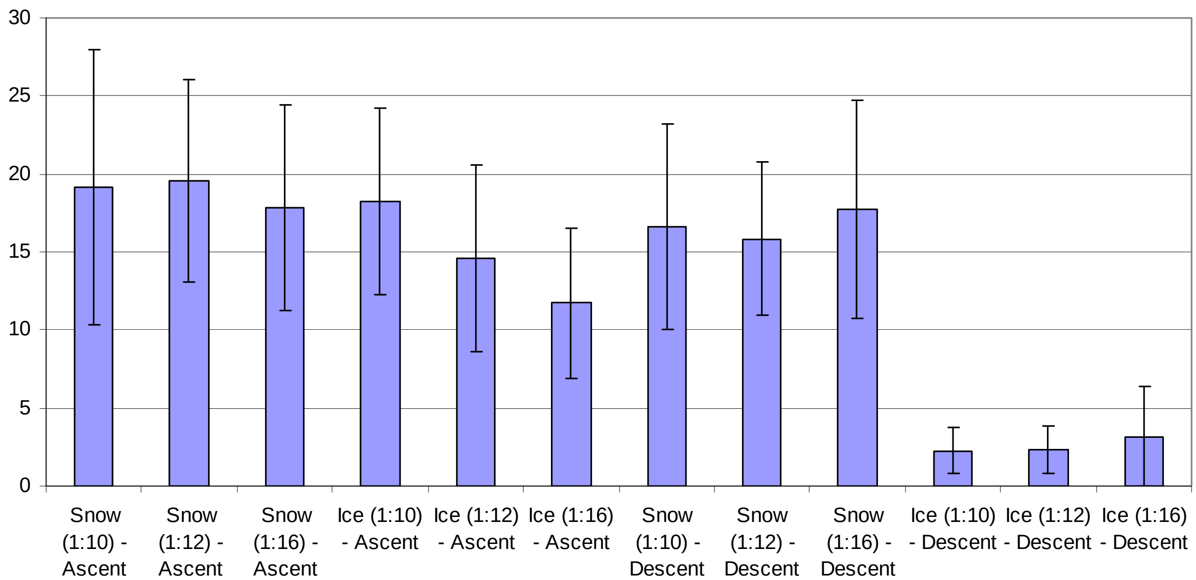


Figure 18: Propulsive stroke count.

For ramp descent in snow, participants had to propel the wheelchair to overcome rolling resistance and obstructions from snow, ruts, etc. In comparison, ice-grit conditions presented minimal resistance for forward wheelchair progression during descent, thereby resulting in few, small propulsive movements (average of 2.6 propulsive movements). These movements were mainly for course correction.

9.7. Strategies

Of the seven strategies that were used to ascend and descend the various ramp conditions, further analysis is warranted for the techniques that were successful for propulsion. These successful strategies included standard ascent, backwards ascent, two-railing ascent, and one-railing ascent. Ramp descent was predominately by standard propulsion on snow and by controlled coasting on ice-grit. One subject mentioned using the brake to apply some pressure on the tire to control descent.

The coasting approach involved minimal motion of the trunk and upper extremities as the hands remained positioned on the wheel rims or followed the railings, thereby maintaining wheelchair trajectory and reducing speed to a manageable level. On snow, low-intensity standard propulsion was required since the snow impeded free wheelchair motion down the ramp, even at 1:10 grade. While only used by three participants, likely due to physical capacity, standard propulsion with wheelie was the most efficient method for ramp descent. Average speed in snow conditions was 0.44 m/s (SD=0.07) when the person was able to raise the front wheels for the entire ramp descent task, compared with 0.22 m/s (SD=0.15) for the other ramp descent in snow conditions strategies.

9.7.1. Standard Propulsion for Ramp Ascent

Standard wheelchair propulsion involves only pushing on the wheel rims for forward progression. One cycle, or stroke, is defined as hand contact on the wheel rim to initiate propulsion to the next propulsion hand contact. Standard propulsion was the predominately strategy for ice-grit trials (Figure 19).

As displayed in Table 9 and Figure 20–Figure 22, for the ice-grit trials, shoulder and elbow ranges of motion increased as ramp slope decreased. Interestingly, the stroke time (i.e., time from initiating propulsion for one cycle to the start of the next propulsive phase) decreased with decreasing ramp angle. Average stroke times for standard ice-grit ascent conditions were 1.19 (SD=0.46) s for 1:10, 1.04 (SD=0.24) s for 1:12, and 0.95 (SD=0.24) s for 1:16. This finding contradicts results from the literature for dry-ramp ascent, where stroke time decreased at steeper ramp angles [13]. The 1:16 ramp grade stroke time was similar to the results from Chow et al. [13] (0.98, SD=0.12), but the 1:10 time for ice-grit was approximately 25% greater than these dry ramp ascent trials. This outcome could be attributed to the need to provide wheelchair rim propulsive forces that do not cause the wheels to slip, over a longer period, to climb the steeper ramp slopes. At the 1:16 grade, the adverse effects of wheel friction on ice-grit were less of a factor, since less propulsive force is needed to ascend the ramp, thereby bringing the results more in line with dry ramp ascent.

Figure 19: Standard ramp ascent strategy.

The shoulder range of motion was lower than level ground wheelchair propulsion results from the literature [24,25]. The 1:10 grade had the largest differences between this study and the average results from the literature, with shoulder flexion/extension averaging 24.5 degrees lower, abduction 3.3 degrees lower, and axial rotation 39.9 degrees lower. The 1:12 and 1:16 grades were similar with results approximately 18 degrees lower for flexion/extension, 2 degrees lower for abduction, and 32 degrees lower for axial rotation.

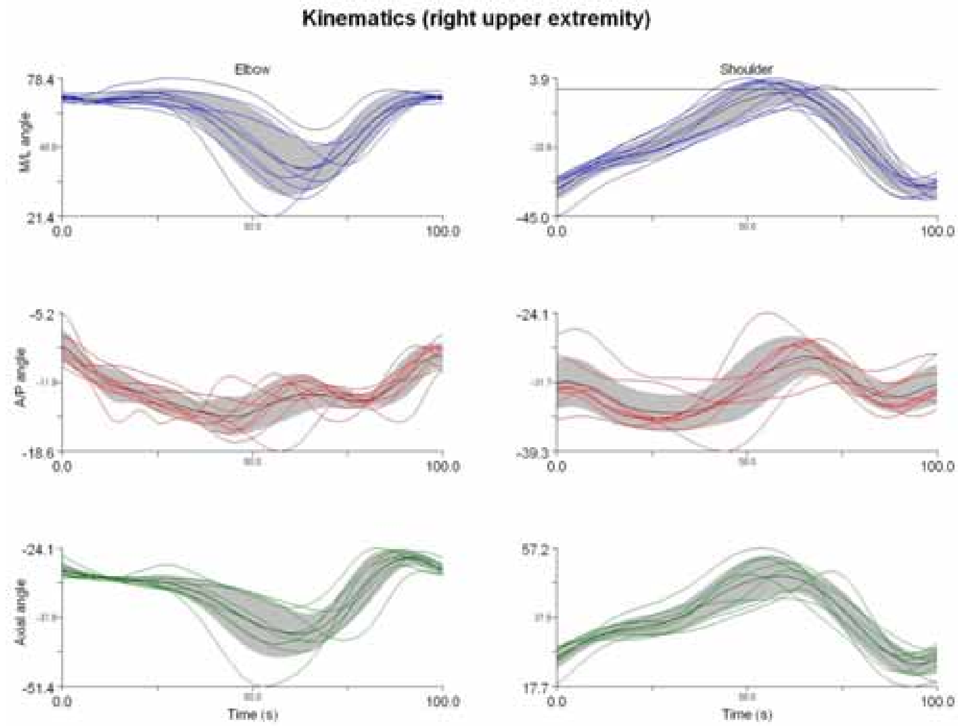


Figure **20**: Shoulder and elbow angles for standard ramp ascent (ice-grit condition, 1:10 grade), initiated from start of propulsion.

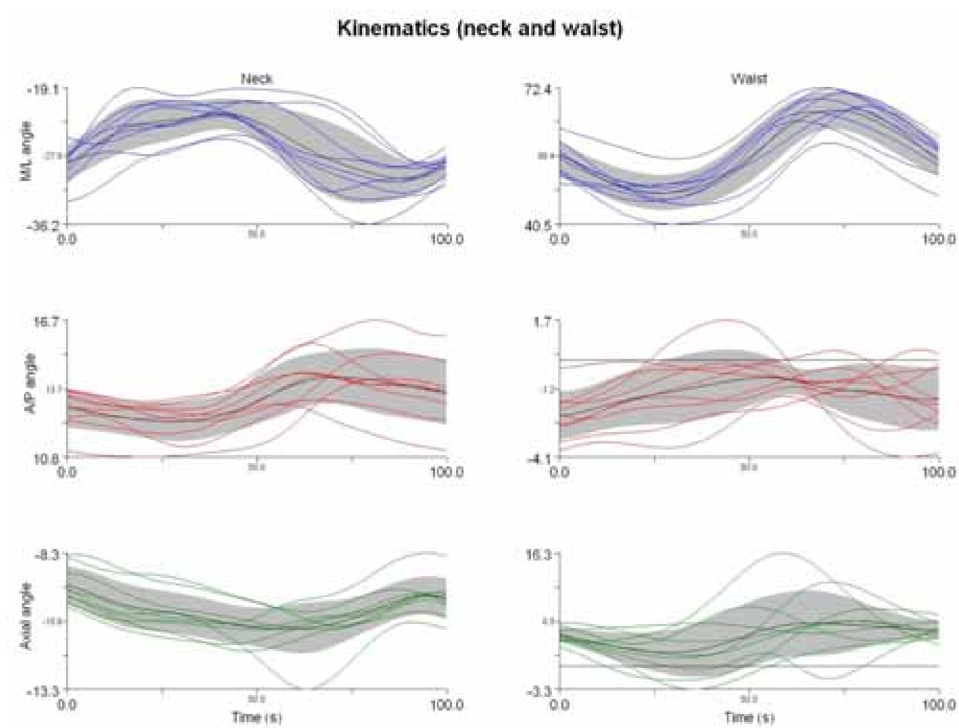


Figure **21**: Trunk and neck angles for standard ramp ascent (ice-grit condition, 1:10 grade), initiated from start of propulsion.

Elbow range of motion was also lower than for level ground kinematic data at the 1:10 grade, but similar at 1:12 and 1:16 [26–28]. The average difference between ice-grit ramp ascent at 1:10 and level ground for elbow range was 11.3 degrees. Less than a 2 degree difference was found for 1:12 and 1:16. Slower and shorter strokes were required to ascend the steeper grade, without wheel slip.

Trunk range of motion was larger than data from the literature, with an average range of approximately 18.5 degrees for all ramp grades. This value was much larger than the typical trunk angles of 11-13 degrees for level ground propulsion [27-29].

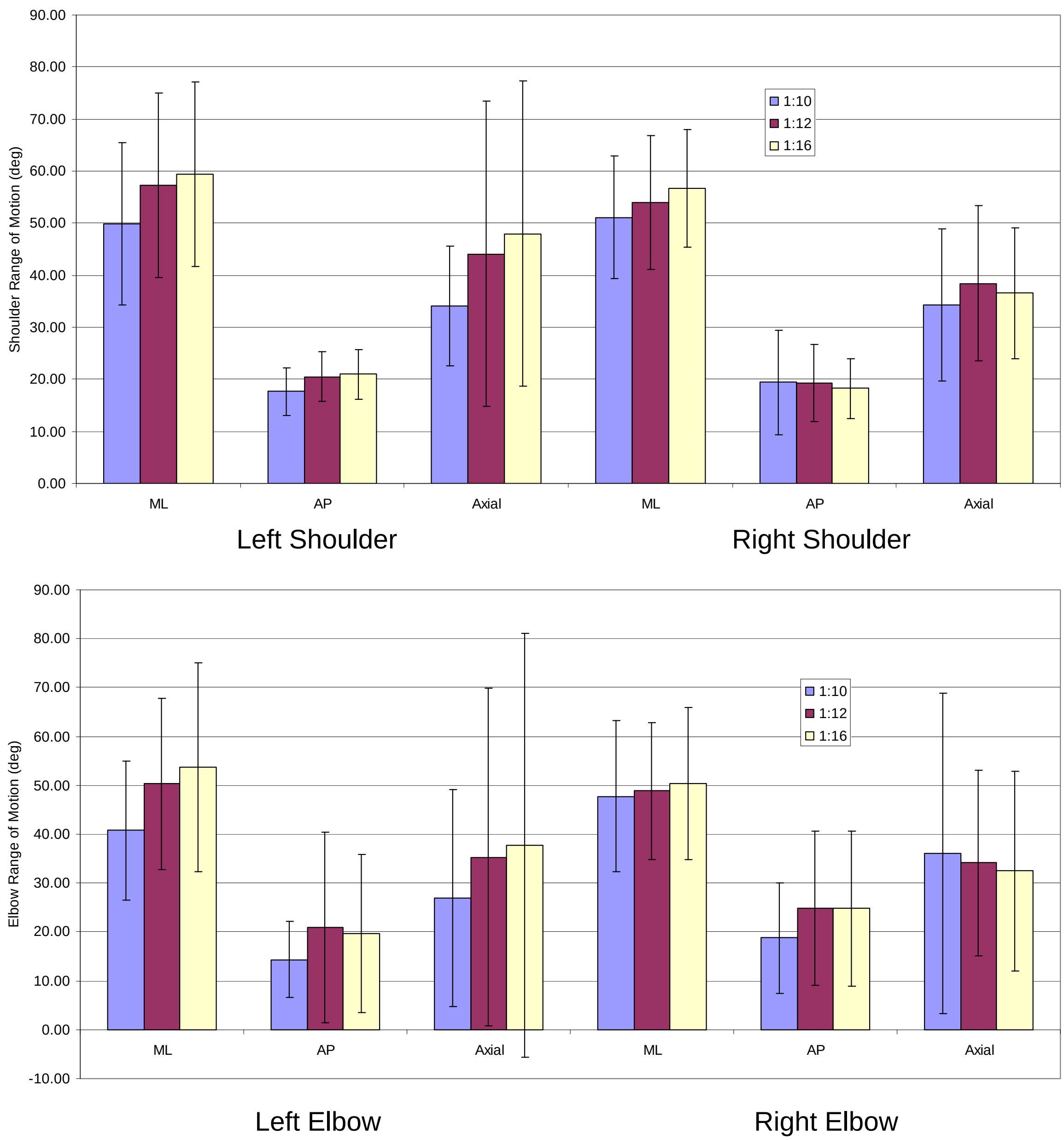


Figure 22: Shoulder and elbow range of motion by grade for standard ramp ascent on ice-grit.

Table 9: Shoulder, elbow, and trunk angles (average and standard deviation) in degrees for standard ramp ascent in ice conditions.

				Flexion/Extension	Abduction	Axial Rotation
1:10	Left	Shoulder	Max	17.16 (9.4)	44.57 (5.3)	-22.17 (21.1)
			Min	-32.78 (9.2)	26.93 (6.5)	-56.18 (16.4)
			Range	49.93 (15.6)	17.64 (4.6)	34.01 (11.5)
		Elbow	Max	79.71 (8.2)	10.56 (8.1)	15.81 (33.8)
			Min	38.92 (13.0)	-3.79 (7.9)	-11.14 (26.8)
			Range	40.79 (14.2)	14.35 (7.8)	26.95 (22.2)
	Right	Shoulder	Max	15.41 (13.8)	-25.93 (6.3)	39.94 (21.7)
			Min	-35.73 (6.5)	-45.38 (6.7)	5.59 (16.1)
			Range	51.13 (11.8)	19.46 (10.0)	34.36 (14.6)
		Elbow	Max	81.88 (8.6)	15.32 (17.7)	-4.43 (30.7)
			Min	34.13 (15.9)	-3.47 (14.4)	-40.53 (17.7)
			Range	47.75 (15.4)	18.79 (11.3)	36.10 (32.8)
		Trunk	Max	69.01 (8.8)	2.82 (2.5)	3.86 (4.9)
			Min	50.93 (9.3)	-1.68 (2.0)	-4.95 (6.4)
			Range	18.08 (6.6)	4.50 (2.1)	8.81 (4.9)
1:12	Left	Shoulder	Max	21.88 (11.7)	44.95 (5.0)	-14.90 (35.7)
			Min	-35.44 (10.0)	24.44 (7.3)	-58.95 (14.7)
			Range	57.32 (17.8)	20.51 (4.8)	44.06 (29.3)
		Elbow	Max	78.91 (9.3)	10.64 (8.8)	19.95 (39.9)
			Min	28.61 (12.2)	-10.23 (17.0)	-15.37 (34.7)
			Range	50.30 (17.6)	20.87 (19.5)	35.32 (34.6)
	Right	Shoulder	Max	15.64 (13.3)	-24.54 (6.9)	35.23 (24.0)
			Min	-38.29 (7.4)	-43.78 (5.0)	-3.24 (22.3)
			Range	53.93 (12.9)	19.24 (7.4)	38.47 (14.9)
		Elbow	Max	81.94 (9.8)	23.72 (24.0)	-11.33 (17.7)
			Min	33.04 (12.7)	-1.20 (14.9)	-45.45 (13.0)
			Range	48.90 (14.0)	24.92 (15.8)	34.12 (19.0)
		Trunk	Max	70.48 (7.4)	1.74 (2.1)	3.19 (5.6)
			Min	51.23 (8.7)	-2.02 (1.9)	-4.21 (5.0)
			Range	19.25 (5.5)	3.76 (1.8)	7.40 (3.1)
1:16	Left	Shoulder	Max	22.31 (11.4)	43.35 (5.7)	-12.49 (40.9)
			Min	-37.13 (11.2)	22.36 (6.8)	-60.51 (19.3)
			Range	59.44 (17.0)	20.98 (5.2)	48.01 (28.9)
		Elbow	Max	78.70 (8.8)	7.88 (9.7)	22.45 (42.1)
			Min	25.04 (16.3)	-11.73 (14.0)	-15.25 (37.8)
			Range	53.65 (21.4)	19.60 (16.2)	37.70 (43.3)
	Right	Shoulder	Max	16.82 (12.7)	-24.07 (6.5)	32.62 (23.6)
			Min	-39.83 (7.7)	-42.34 (5.4)	-3.99 (25.8)
			Range	56.65 (11.3)	18.27 (5.7)	36.60 (12.6)
		Elbow	Max	80.48 (11.3)	24.59 (25.6)	-14.17 (18.8)
			Min	30.08 (12.8)	-0.17 (15.2)	-46.64 (17.6)
			Range	50.40 (15.6)	24.77 (15.9)	32.46 (20.4)
		Trunk	Max	74.11 (9.7)	2.33 (2.0)	3.03 (5.3)
			Min	55.67 (9.5)	-1.76 (1.3)	-2.44 (5.6)
			Range	18.44 (5.8)	4.10 (1.8)	5.48 (2.1)

9.7.2. Backwards Strategy for Ramp Ascent

Backwards ramp ascent was a successful strategy that was used by one subject for snow conditions. This subject pushed on both handrails simultaneously to propel the wheelchair backwards up the ramp. As shown in Table 10 and Figure 23, for the 1:10 ramp grade, the shoulder required approximately 107 degrees of extension and 30 degrees of abduction to perform the main propulsive phase (i.e., from grasp of the railing behind the wheelchair to the end of forward hand progression). The maximum right shoulder flexion/extension angular velocity averaged 724.0 deg/s, with a maximum of 603.6 deg/s for the left arm, over this period. The 1:12 grade results were similar, but the maximum propulsive shoulder angular velocities were lower for the 1:16 grade (average of 392.4 deg/s for right arm and 460.5 deg/second for the left arm). The shoulder range of motion used for this approach was in the normal range, and therefore should be accessible for people without restrictive shoulder problems.

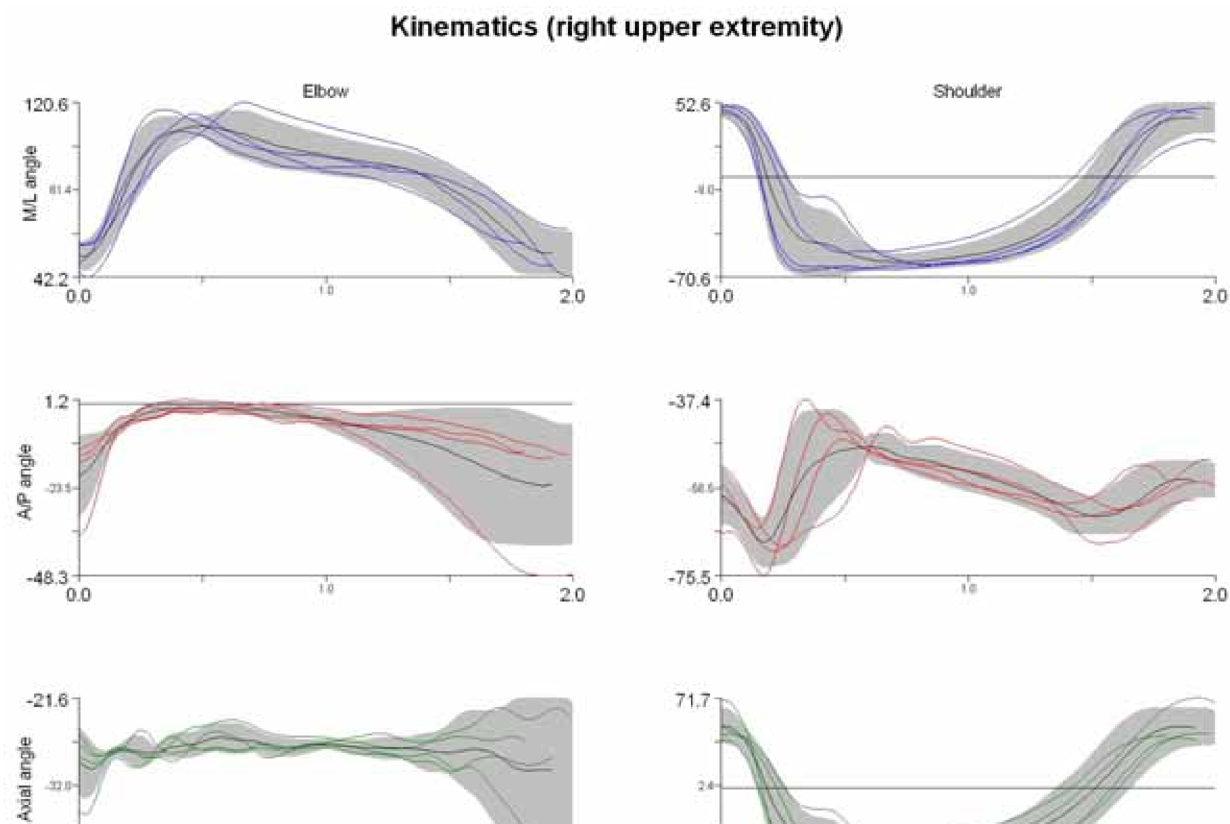


Figure **23**: Shoulder and elbow angles for backwards ramp ascent (snow condition, 1:10 grade), initiated from railing grasp, through propulsion, to railing regrasp. Standard deviation is in gray. The average curve is in bold.

The upper trunk angle, relative to the wheelchair seat, had a small range of 10 degrees at the 1:10 grade (Figure 24). This range was consistent with maximum trunk flexion at the initiation of the propulsive phase. In contrast with typical wheelchair propulsion, the trunk flexed to position the hands on the railings then extended during the propulsive phase.

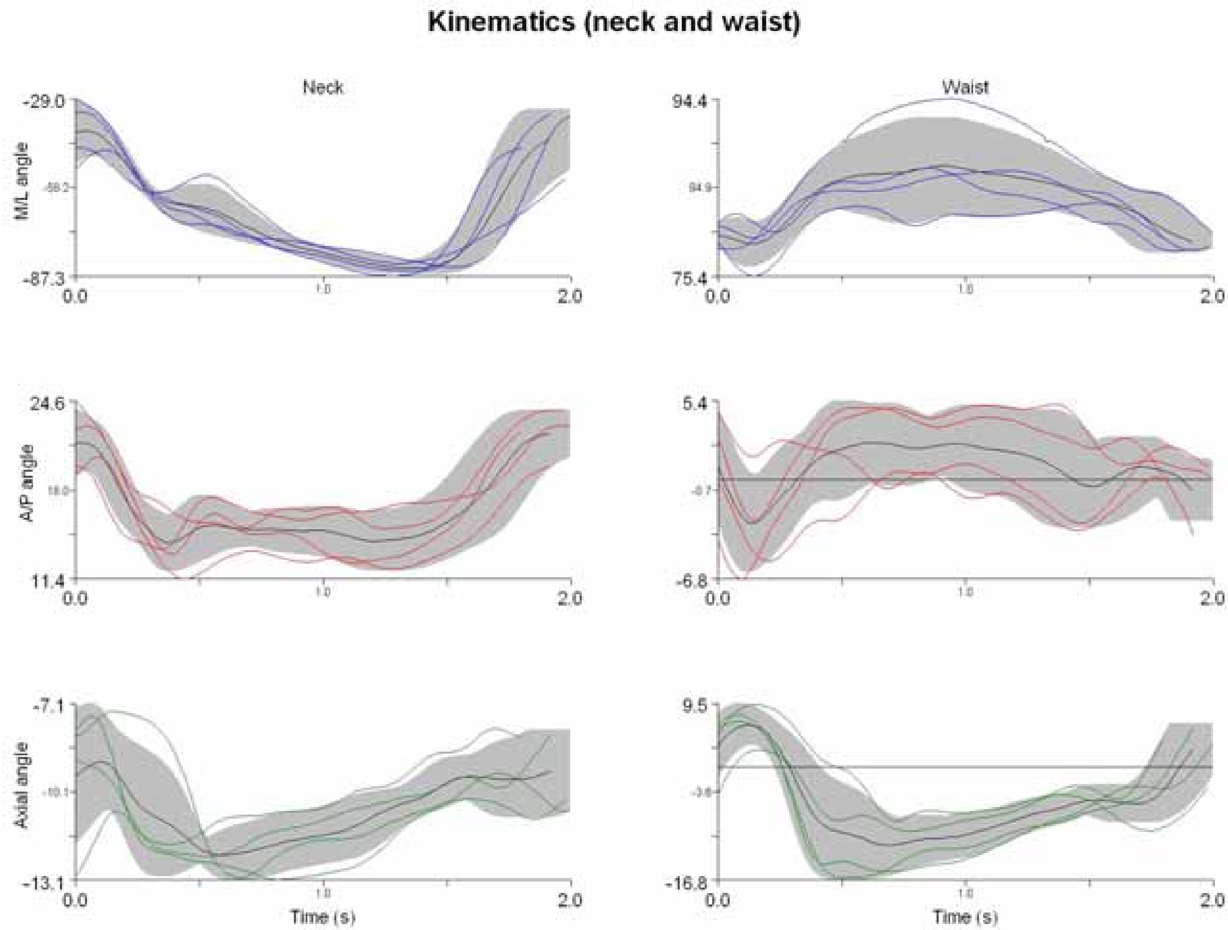


Figure **24**: Trunk and neck angles for backwards ramp ascent (snow condition, 1:10 grade), initiated from railing grasp, through propulsion, to railing regrasp. Standard deviation is in gray. The average curve is in bold.

The largest trunk flexion/extension range was for the 1:12 grade (12.6 deg.); however, the forward angle was still over 70 degrees to the seat plane. The shape of the 1:12 and 1:16 trunk angle curves were similar (Pearson r=0.98), but with an offset averaging 7.5 deg (Figure 25).

The ability to accomplish the ramp ascent task with less trunk flexion could be of benefit for some wheelchair users. Standard technique for 1:10 snow ascent required 20 degrees more flexion than backwards ascent.

Table 10: Shoulder, elbow, and trunk angles (average and standard deviation) in degrees for backwards ramp ascent in snow conditions.

				Flexion/Extension	Abduction	Axial Rotation
1:10	Left	Shoulder	Max	32.16 (12.6)	77.89 (2.2)	69.55 (2.5)
			Min	-73.17 (2.7)	37.14 (5.0)	-34.84 (13.7)
			Range	105.33 (14.3)	40.75 (2.9)	104.38 (14.8)
		Elbow	Max	57.01 (4.1)	10.94 (2.0)	-32.25 (2.0)
			Min	32.80 (7.5)	0.24 (4.1)	-37.48 (0.7)
			Range	24.21 (5.4)	10.69 (3.5)	5.24 (2.3)
	Right	Shoulder	Max	48.01 (3.5)	70.02 (4.2)	58.46 (14.4)
			Min	-61.71 (5.9)	41.80 (3.7)	-56.05 (8.0)
			Range	109.73 (3.8)	28.22 (5.0)	114.50 (21.7)
		Elbow	Max	115.21 (5.6)	29.18 (16.4)	-24.99 (1.6)
			Min	49.60 (8.1)	0.14 (1.1)	-33.91 (6.5)
			Range	65.61 (6.3)	29.04 (16.9)	8.92 (5.9)
		Trunk	Max	87.84 (4.7)	4.28 (1.4)	7.05 (2.1)
			Min	77.78 (1.7)	-4.91 (1.6)	-12.65 (3.8)
			Range	10.06 (4.1)	9.18 (1.9)	19.70 (4.5)
1:12	Left	Shoulder	Max	62.23 (4.7)	75.40 (4.1)	76.51 (3.9)
			Min	-69.72 (3.5)	31.85 (6.7)	-39.28 (6.9)
			Range	131.95 (7.7)	43.55 (9.7)	115.79 (10.7)
		Elbow	Max	91.19 (9.7)	5.66 (2.5)	-40.06 (2.1)
			Min	46.73 (0.8)	-21.22 (4.6)	-57.99 (2.2)
			Range	44.46 (10.4)	26.88 (6.2)	17.93 (2.6)
	Right	Shoulder	Max	56.28 (5.1)	73.89 (5.3)	74.72 (5.0)
			Min	-68.38 (3.4)	31.32 (3.8)	-51.32 (4.1)
			Range	124.67 (7.3)	42.57 (4.6)	126.04 (4.3)
		Elbow	Max	114.79 (8.9)	-1.05 (4.5)	-18.07 (3.4)
			Min	41.67 (3.2)	-17.45 (0.6)	-27.16 (1.7)
			Range	73.13 (7.0)	16.40 (5.0)	9.09 (1.8)
		Trunk	Max	92.70 (2.8)	6.34 (4.8)	10.84 (1.6)
			Min	71.04 (4.9)	-2.74 (2.7)	-7.11 (6.6)
			Range	21.66 (6.3)	9.08 (3.5)	17.95 (5.2)
1:16	Left	Shoulder	Max	41.72 (3.5)	66.83 (0.8)	68.85 (19.1)
			Min	-65.87 (3.2)	31.80 (3.0)	-40.89 (16.8)
			Range	107.59 (4.0)	35.04 (2.7)	109.74 (3.5)
		Elbow	Max	96.76 (4.9)	11.78 (1.2)	-35.59 (2.7)
			Min	43.37 (3.5)	-2.60 (2.3)	-44.08 (1.1)
			Range	53.39 (8.4)	14.38 (1.2)	8.49 (1.7)
	Right	Shoulder	Max	44.84 (3.5)	-5.66 (0.8)	46.38 (19.1)
			Min	-63.42 (3.2)	-31.70 (3.0)	-58.59 (16.8)
			Range	108.26 (4.0)	26.03 (2.7)	104.96 (3.5)
		Elbow	Max	115.04 (9.5)	-4.76 (0.5)	-18.77 (1.0)
			Min	49.04 (0.8)	-15.95 (1.9)	-26.61 (1.9)
			Range	66.00 (10.3)	11.19 (1.5)	7.84 (1.0)
		Trunk	Max	97.35 (1.4)	9.75 (2.6)	10.39 (1.8)
			Min	83.36 (2.4)	1.10 (0.9)	-5.54 (5.9)
			Range	14.00 (2.5)	8.65 (1.8)	15.94 (7.1)

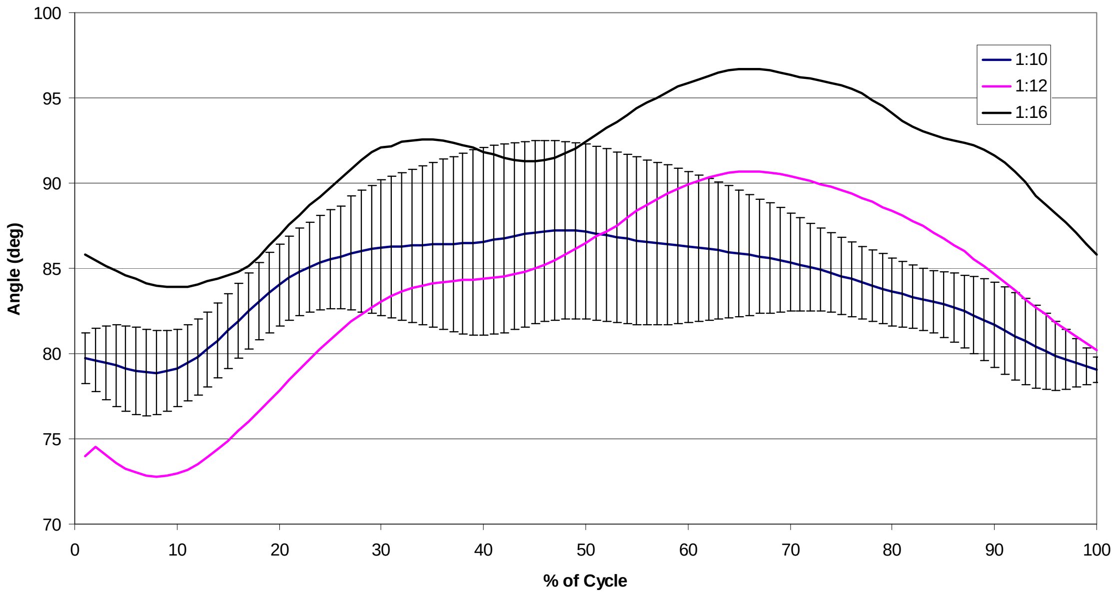


Figure 25: Trunk flexion angle by grade. One standard deviation shown for the 1:10 grade.

Figure 27 compares the shoulder and elbow ranges of motion by ramp grade. The shoulder range of motion was consistently higher for the 1:12 grade. Similarly, elbow range of motion results at 1:12 were larger for all except left elbow flexion/extension and right elbow abduction. Further research is needed, with a larger group people using backwards ascent, to determine if this result is related to grade or part of the expected biomechanical variance for this task.

Figure 26: Backwards ramp ascent strategy.

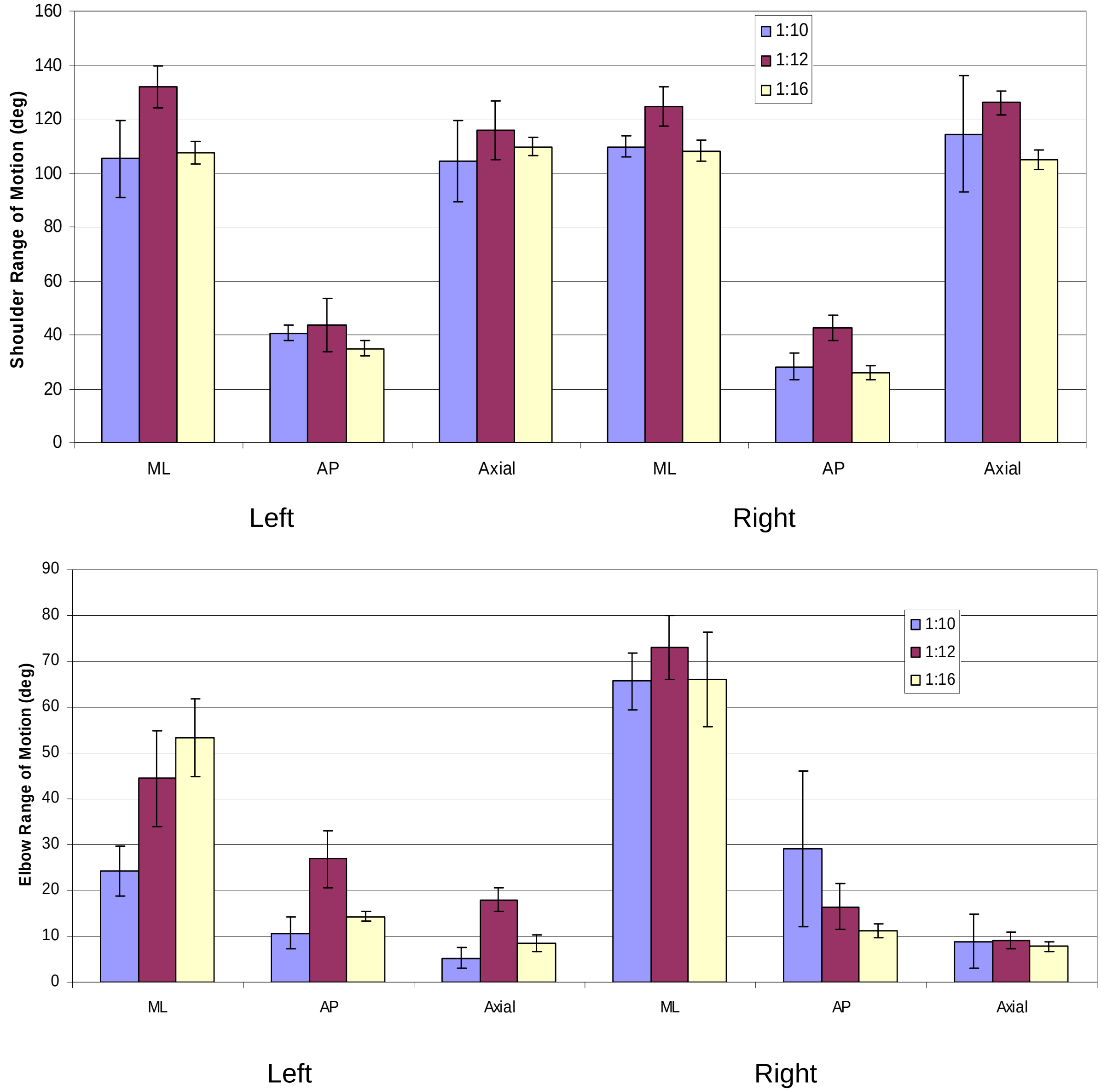


Figure **27**: Shoulder and elbow range of motion by grade for backwards ramp ascent on snow.

9.7.3. Two Railing Ascent

Simultaneously pulling on the two railings was used for ramp ascent with varying success. In snow conditions, subjects must be able to pull on the railings while simultaneously offloading the front casters; otherwise, the casters are embedded further into the snow and the wheelchair rotates over the front wheels. The majority of attempts to use two-railing propulsion in the snow conditions (predominately 1:10) were only successful in repositioning the wheelchair to release the front wheels from the snow and reinitiate ramp ascent. However, various subjects were able to use this technique for short ranges on the ramp (typically at the top section). Figure 29, Figure 30, and Table 11 show representative data for the shoulder, elbow and trunk while successfully completing a two-railing propulsive motion for ramp ascent in snow conditions. A larger range of shoulder motion was found for forward railing ascent, as compared with backwards ascent. The increase range, particularly at the 1:10 grade, was due to increased shoulder flexion at the initiation of the propulsive phase. This initial left shoulder flexion angle decreased by approximately 40% for the 1:12 and 1:16 grades. Right shoulder flexion decreased by 10% over the same conditions.

The trunk remained in a flexed position throughout successive two-railing propulsion cycles, with a maximum of approximately 37 deg flexion at the initiation of the propulsion phase. Trunk flexion-extension range of motion increased as ramp grade decreased, 17.5% decrease from 1:10–1:12 and 25.7% decrease from 1:12-1:16. The larger seat angle at the steeper grade should account for these differences.

Figure 28: Two-railing ascent strategy on ice.

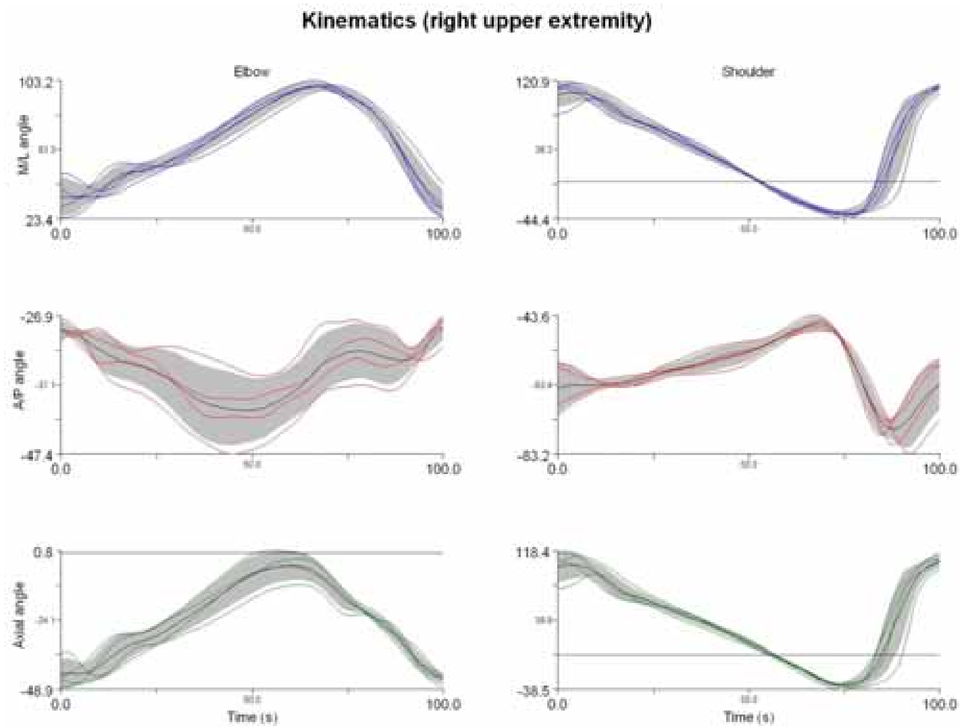


Figure **29**: Shoulder and elbow angles for two-railing ramp ascent (snow condition, 1:10 grade), initiated from railing grasp, through propulsion, to railing regrasp.

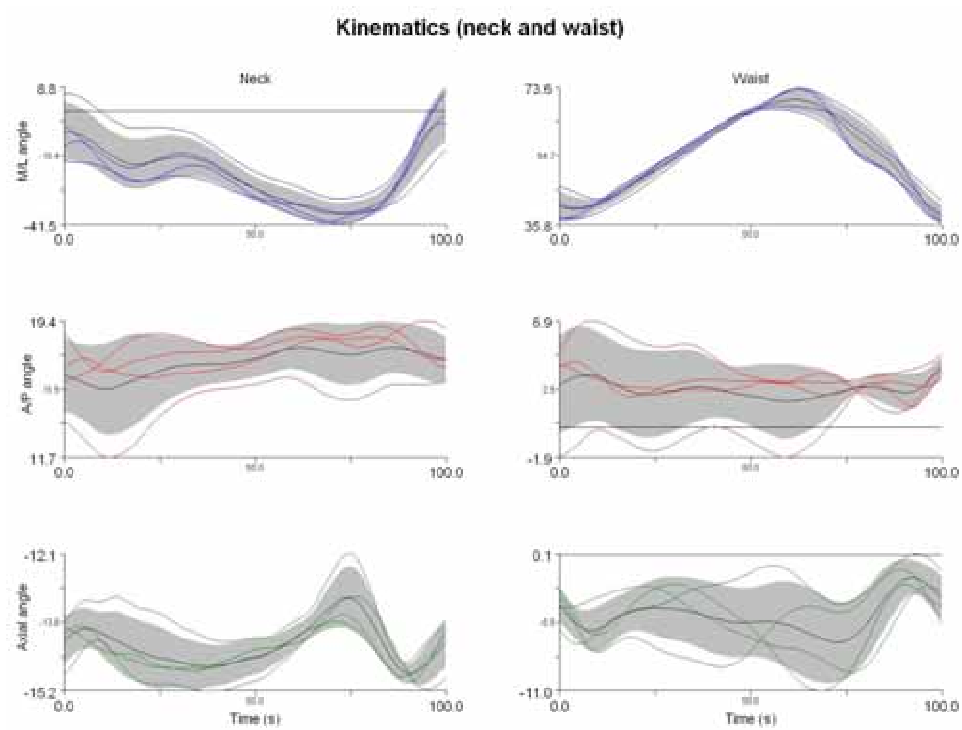


Figure **30**: Trunk and neck angles for two-trailing ramp ascent (snow condition, 1:10 grade), initiated from railing grasp, through propulsion, to railing regrasp.

Table **11**: Shoulder, elbow, trunk angles (average and standard deviation) in degrees for two-railing ramp ascent in snow conditions. One trial was processed at 1:16 grade (i.e., no SD).

				Flexion/Extension	**Abduction**	**Axial Rotation**
1:10	Left	Shoulder	Max	104.73 (8.8)	78.41 (0.8)	59.94 (1.8)
			Min	-46.73 (1.0)	33.84 (2.1)	-86.76 (10.4)
			Range	151.46 (8.6)	44.57 (2.5)	146.70 (8.7)
		Elbow	Max	82.40 (1.7)	23.55 (2.8)	-36.79 (0.5)
			Min	22.58 (1.2)	15.51 (1.6)	-66.13 (0.8)
			Range	59.82 (0.6)	8.04 (3.0)	29.33 (0.5)
	Right	Shoulder	Max	114.47 (3.2)	-45.90 (1.9)	111.63 (4.5)
			Min	-39.34 (3.8)	-78.80 (4.1)	-35.01 (2.9)
			Range	153.81 (3.1)	32.90 (4.5)	146.64 (2.0)
		Elbow	Max	100.15 (2.4)	-27.86 (0.7)	-4.42 (5.3)
			Min	27.38 (3.5)	-41.12 (4.9)	-46.36 (2.1)
			Range	72.77 (5.4)	13.26 (5.2)	41.94 (7.0)
		Trunk	Max	70.55 (3.0)	4.80 (1.4)	-1.47 (1.2)
			Min	37.16 (0.6)	0.78 (1.9)	-9.22 (1.6)
			Range	33.39 (2.6)	4.02 (2.0)	7.75 (0.7)
1:12	Left	Shoulder	Max	60.89 (4.2)	73.18 (5.9)	54.85 (9.2)
			Min	-41.85 (8.0)	39.72 (6.2)	-30.06 (3.2)
			Range	102.74 (7.4)	33.47 (11.5)	84.91 (8.0)
		Elbow	Max	97.27 (2.7)	24.50 (3.1)	-48.87 (5.0)
			Min	44.13 (4.5)	11.25 (5.7)	-79.84 (1.9)
			Range	53.15 (2.2)	13.25 (4.3)	30.97 (6.1)
	Right	Shoulder	Max	97.96 (6.1)	-47.57 (7.3)	88.98 (3.1)
			Min	-35.93 (10.6)	-75.97 (5.9)	-24.36 (11.6)
			Range	133.89 (15.3)	28.40 (3.7)	113.34 (13.8)
		Elbow	Max	94.44 (5.2)	-26.06 (7.2)	-2.40 (2.6)
			Min	39.67 (3.2)	-38.55 (3.2)	-37.20 (3.9)
			Range	54.77 (4.4)	12.49 (5.6)	34.80 (4.2)
		Trunk	Max	82.09 (3.8)	5.05 (0.9)	1.27 (1.6)
			Min	41.60 (6.1)	0.38 (0.5)	-3.84 (2.6)
			Range	40.49 (4.4)	4.67 (1.1)	5.11 (1.4)
1:16	Left	Shoulder	Max	65.49	78.06	64.70
			Min	-42.16	28.19	-34.09
			Range	107.65	49.87	98.79
		Elbow	Max	108.04	20.36	-46.43
			Min	40.11	13.32	-81.30
			Range	67.93	7.05	34.87
	Right	Shoulder	Max	99.92	79.34	82.75
			Min	-44.05	37.12	-45.97
			Range	143.97	42.22	128.72
		Elbow	Max	93.54	-28.29	-11.05
			Min	54.52	-36.46	-42.23
			Range	39.03	8.17	31.18
		Trunk	Max	89.26	8.79	-0.63
			Min	34.74	-1.38	-7.24
			Range	54.51	10.17	6.61

For ice conditions, all but one subject used the two-railing ascent strategy for a single propulsive phase to reinitiate progression and, if needed, to reposition the wheelchair during this propulsive manoeuvre. This typically followed a standard propulsive movement where the wheels slipped. At the 1:10 grade, some subjects used two-railing strategy for the final propulsion movement before reaching the top of the ramp.

9.8. Wheelie Descent

The wheelie descent strategy was used in snow conditions to clear the front wheels while descending the ramp (i.e., descend ramp on the back two wheels – Figure 31). Only the higher activity subjects were able to accomplish this task. Propulsive strokes were required to descent the ramp and control seat angle on the irregular ramp surface.

Figure 31: Wheelie strategy for ramp descent.

As shown in Figure 32, Figure 33 and Table 12, the trunk range of motion was small in comparison with the ramp ascent trials (approximately one third of the range for ramp ascent). Range of motion for the shoulder and elbow were also lower than the related data for standard wheelchair ascent in snow conditions, at all angles.

The seat angle was surprisingly consistent during wheelie descent, with an average of 24.3 degrees (SD=2.6) for seat tilt and 2.2 degrees (SD=2.6) for side-to-side seat rotation, with respect to the room (i.e., angle between seat and horizontal). The seat angular velocity averaged 0.14 deg/s (SD=0.10) for seat tilt and 0.07 deg/s (SD=0.06) for side-to-side seat rotation.

Table 12: Shoulder, elbow, and trunk angles (average and standard deviation) in degrees for wheelie ramp descent in snow conditions at 1:10 grade.

			Flexion/Extension	**Abduction**	**Axial Rotation**
Left	Shoulder	Max	9.90 (4.3)	31.48 (2.5)	0.71 (4.5)
		Min	-34.00 (3.9)	21.73 (1.6)	-29.87 (4.3)
		Range	43.90 (6.4)	9.75 (2.7)	30.58 (5.9)
	Elbow	Max	81.24 (2.7)	13.68 (1.5)	-47.06 (1.7)
		Min	44.15 (5.4)	1.65 (2.0)	-54.54 (1.3)
		Range	37.09 (5.7)	12.03 (2.2)	7.48 (1.4)
Right	Shoulder	Max	4.05 (4.5)	-24.97 (1.7)	29.93 (4.5)
		Min	-34.24 (4.0)	-31.31 (2.7)	4.53 (3.1)
		Range	38.29 (6.8)	6.34 (1.9)	25.40 (5.7)
	Elbow	Max	84.26 (1.6)	2.03 (2.0)	-32.58 (2.1)
		Min	55.65 (7.3)	-12.25 (4.1)	-39.44 (2.9)
		Range	28.61 (7.4)	14.28 (3.6)	6.85 (2.2)
	Trunk	Max	73.89 (2.1)	1.00 (2.3)	4.05 (2.8)
		Min	68.66 (2.3)	-3.23 (1.9)	-3.11 (2.3)
		Range	5.23 (2.1)	4.24 (1.9)	7.16 (2.5)

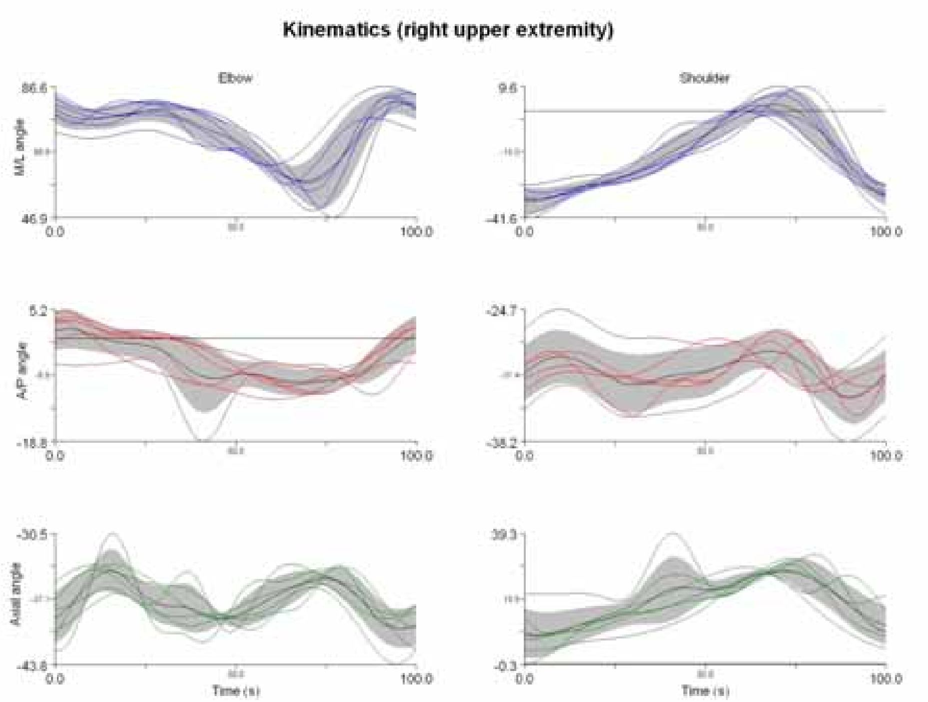


Figure 32: Shoulder and elbow angles for wheelie ramp descent (snow condition, 1:10 grade).

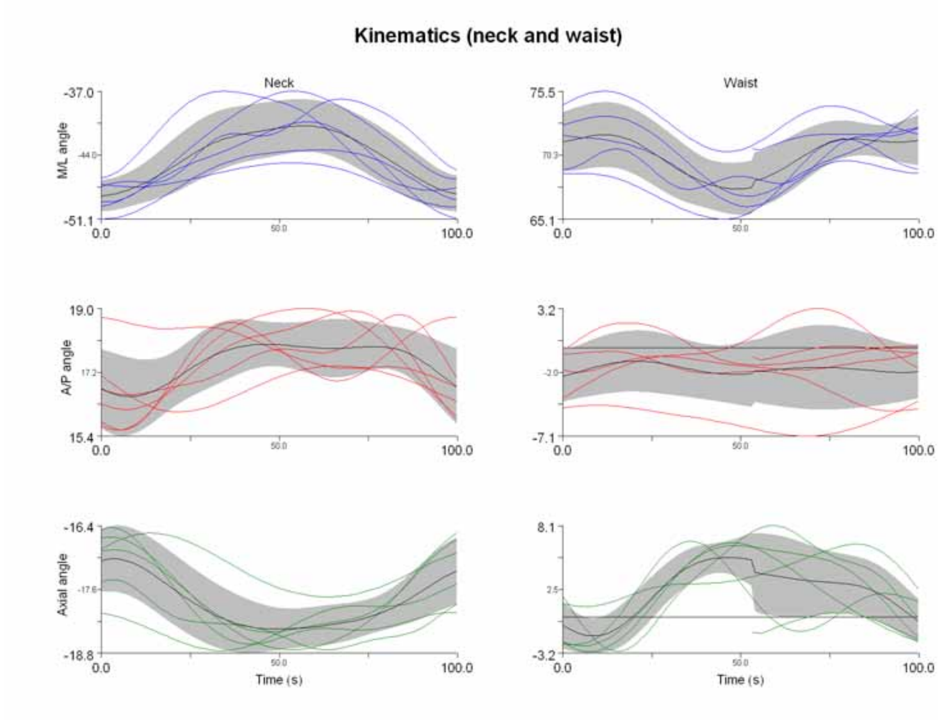


Figure 33: Trunk and neck angles for wheelie ramp descent (snow condition, 1:10 grade).

10. Conclusions

This study confirms the need for research on mobility in winter. While research on this broad topic is in its infancy, the focus of this study on ramp negotiation in snow and ice-grit conditions has provided insight and knowledge to help improve mobility in this target area.

For people who must manually propel a wheelchair through snow and ice conditions, various biomechanical and environmental factors influence successful ramp negotiation. Outcomes from this study confirm that, using standard propulsion techniques, independence cannot to be assumed for all conditions and ramp grades that are accepted under current building codes.

In terms of ramp grade, all subjects were able to complete the ice-grit conditions independently at all ramp slopes. The ice covered snow created a firm, but uneven, surface that eliminated issues where the wheels became embedded in the snow. Sufficient grit was used to provide a safe environment for walking and wheeling on the surface. However, subjective feedback from the participants indicated that insufficient grit, or other material, are typically applied to exterior ramps, thereby creating an unsafe condition or inaccessible ramp (i.e., due to wheel slip on the ice).

Even with sufficient grit, the more active subjects frequently had wheel slip issues during ascent at the 1:10 and 1:12 slopes (i.e., stronger propulsive motion surpasses wheel-ice-grit friction). These subjects typically used a two-railing approach to reinitiate motion and then reverted to standard propulsion. Recommendations could be made to use 2-railing propulsion under ice conditions since friction issues are resolved (i.e., no propulsive force on wheel rims), control of wheelchair trajectory is improved, and a stronger propulsive force can be generated.

Snow conditions produced a much different scenario across ramp grades. The 1:10 grade was insurmountable for many subjects without assistance. As mentioned previously, the main issue was the front wheels becoming embedded in the snow. Without the ability to lean back, clear the front wheels from the snow, and propel the wheelchair forward (at the steeper 1:10 grade), external assistance to clear the wheels from the rut was the only way to reinitiate forward progression.

Interestingly, no relationship was found between front wheel size and success on snow conditions. Subjects using wheelchairs with larger/wider front wheels had the same problems as people using smaller wheels. While therapists prescribing wheelchairs may intuitively recommend wider front wheels for people who propel their manual wheelchair in winter, the results from this study indicate that a much larger increase in dimensions, as compared with typical front casters on the market, would be required to have a substantial effect. Further research is required to understand the wheel dimension threshold beyond which a positive effect would be found.

An important element to consider for snow and exterior ramps is the transition area from level ground to incline and areas where movement is initiated. Even with snow maintenance between trials (i.e., redistributing and tamping the snow onto the ramp), the snow rapidly became softer over the initial 2 metre transition area. The impact of the front wheels on the packed snow, as the wheelchair moves from level ground onto the ramp, breaks the packed snow until it is unable to maintain a solid base. As the front wheels become embedded in ruts in the ramp surface, spinning of the rear wheels continued to erode the packed surface. A similar, but less severe situation occurred at the transition from incline to level surface at the top of the ramp. While this softer snow was not a factor in this study, the implications for longer ramps with transitional areas in the middle should be considered in future work.

The “soft snow area” was consistent with qualitative feedback from wheelchair users who frequently mention difficulties with this transitional area at the bottom of exterior ramps. In most cases, even if the level ground area is relatively clear of snow, accumulation of soft snow at the bottom of exterior ramps stops forward progression, thereby removing any momentum that can facilitate ramp ascension. Since this occurrence was unavoidable even in a controlled environment, new approaches should be considered for ramp designs, ramp maintenance standards, and client practices. Future research should include a “breaking-in” period until a consistent snow condition is achieved (i.e., running multiple wheelchair ascent/descent trials before testing the first subject).

Subjects who were unable to independently navigate the soft initial transition area started one-quarter of the way up the ramp. Even when avoiding the bottom transition area, most subjects had difficulty initiating and propelling up the 1:10 slope, with two subjects being unable to complete the task and many requiring assistance from the research team to free the front wheels from the snow and reposition the wheelchair up the ramp on a more solid section. While mild difficulties were experienced in snow at the 1:12 and 1:16 grades, participants were able to navigate these grades independently.

The one subject who successfully ascended the ramp backwards, at all grades, demonstrated the effectiveness of this strategy. Since this subject was at a moderate functional level, the backwards strategy could be applicable for most people who manually propel their wheelchair in winter. The shoulder and trunk ranges of motion were also within a typical range. More research on backwards ascent is warranted to verify how this approach can be used by lower functioning wheelchair users and to determine if wheelchair and environmental issues exist when extended to a larger population.

Qualitative feedback from study subjects provided interesting considerations for winter wheelchair use. Since poor grip was cited as a major concern during winter, improvements to gloves should universally help wheelchair users in winter environments. Commercially available gloves become slippery as they get wet and do not provide an adequate moisture barrier for winter use. During winter, constant hand interaction with snow, water, salt, etc. is unavoidable when using the wheelchair wheels and rims. Future research is required to develop a low profile winter glove with appropriate water barrier and grip characteristics for wheelchair propulsion.

In terms of experimental considerations, the National Research Council, Centre for Surface Transportation Technology, Climate Engineering Facility was shown to be a viable environment for controlled research on mobility in winter conditions. However, the logistical realities of maintaining consistent snow and ice conditions have lead to the following insights for future research:

- More testing time would be required in the Climate Chamber for subsequent studies to reduce the number of subjects tested per day to a maximum of six and to allow maintenance days for additional snowmaking, etc.
- Testing must allow for weekends and evenings to accommodate wheelchair users with full-time jobs (i.e., although this would potentially increase project the costs due to overtime payments at the NRC facility).
- Focussing on one winter condition would be beneficial since subjects would not have to return for additional testing (i.e., a person may volunteer to participate if they only need to take a half-day off work).
- Revised Vicon camera fixtures should be investigated. Vibrations on the walls, due to cooling and high capacity ventilation systems, may have contributed to subtle camera movement that adversely affected system calibration. Vicon calibration was required after each group completed their trials, likely related to camera movement.

Based on the quantitative and qualitative outcomes from this study, the 1:16 ramp grade is recommended to allow broad, independent accessibility by wheelchair users. While sufficient evidence was not obtained to recommend removal of 1:10 ramp grades from exterior building standards, snow accumulation on ramps at 1:10 grade will render the ramp inaccessible for many wheelchair users who do not have external assistance. Future research should include improved designs for transition area at the ramp bottom, determination of optimal wheelchair components and wheelchair configuration for snow and ice conditions, and improved gloves for winter wheelchair propulsion. Since the modular ramp used in this study allowed some flexion and movement during propulsion that could have affected snow compaction, providing a more difficult environment where the wheels easily sink into the snow. Research comparing modular and rigid (wood, concrete) ramp materials would provide important information for exterior designs.

In addition to future research on wheelchair mobility in winter, biomechanical research is needed for walking on exterior ramps in snow and ice conditions. As our population ages, more Canadians will use exterior ramps for access to buildings and residences. Safety concerns exist since physical deficits as we age often results in the use of assistive devices (canes, walkers, ankle-foot orthoses/braces, etc.) that affect mobility and who’s function can be adversely affected by snow and ice conditions. These adverse affects are compounded by physical deficits that limit range of motion, muscular strength, motor control, and dynamic stability.

10.1. Summary of Recommendations

- Based on the slightly lower number of difficulties and lowest times to ascend the ramp, the 1:16 grade is preferred for winter ramp navigation.
- For snow conditions, the transition area from level group to the first 2m of ramp incline were the most difficult to traverse, for both ascent and descent. Guidelines for design and maintenance of this area are recommended to improve accessibility and independence.
- For ice-grit ramp navigation, two-railing propulsion is a preferred strategy due to enhanced trajectory control and reducing the potential for wheel slip problems.
- Backwards ramp ascent for snow conditions should be considered for people with sufficient shoulder and trunk range of motion, although further research should be performed to verify that the successful outcomes can be generalized beyond the single subject results in this study.
- Two handrails are recommended for exterior ramps, for both propulsion and wheelchair extraction from ruts and other snow-related obstacles. Railing design issues are important, considering the enhanced roles for controlling descent, obstacle extraction, and propulsion. Important factors include allowing unobstructed grip throughout the ramp length (i.e., no posts blocking the hand when using the rails to control descent), ensuring railings that are free of snow and ice, etc.
- For ice ramp navigation, the amount of grit required and the effective time (i.e., time to when grit becomes embedded in snow-ice, becoming much less effective) should be addressed in further research.
- Front wheels typically available with manual wheelchairs are not designed for soft snow conditions. Few options exist that attempt to address this need; therefore, further research in this area is warranted.

11. Acknowledgements

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13. Appendix A – Data Collection Forms

Wheelchair Ramp Use Questionnaire

Subject Number	
Date	
Age	
Gender	
Living arrangements	

Please complete the following questions based on **exterior/outdoor** ramps.

1. How long have you used a wheelchair? ____

2. Do you have ramp or lift access to your residence? Select all that apply.

Ramp	Lift	None

3. Please rate your overall capability to safely **ascend/climb** ramps:

	Same as level ground	More difficult than level ground	Very difficult, but I can ascend all ramps	Very difficult, I cannot ascend some ramps	Safe ramp ascent is rarely possible
Spring					
Summer					
Fall					
Winter					

4. Rate your overall capability to safely **descend/go down** ramps:

	Same as level ground	More difficult than level ground	Very difficult, but I can descend all ramps	Very difficult, I cannot descend some ramps	Safe ramp descent is rarely possible
Spring					
Summer					
Fall					
Winter					

5. During winter, what is more challenging:
    a. Safe ramp ascent / climbing
    b. Safe ramp descent

6. Please list your five most challenging barriers for safe wheelchair mobility during winter.

7. How often do you receive assistance when **ascending/climbing** ramps:

	Never	Rarely	Sometimes	Often	Always
Spring					
Summer					
Fall					
Winter					

8. How often do you receive assistance when **descending** ramps:

	Never	Rarely	Sometimes	Often	Always
Spring					
Summer					
Fall					
Winter					

9. How many times have you been injured while using a ramp in winter over the last 5 years?

Never	1-5 times	6-10 times	11-15 times	More than 15 times

   a. Have any of these injuries required a visit to a clinic or hospital?

Yes	No

10. What strategies do you use for using ramps in winter (select all that apply):
    a. Covered ramp or canopy
    b. Gentle ramp slope
    c. I only use a lift in winter
    d. Use handrails as an assist
    e. Slip-resistant ramp surfaces
    f. In-ramp heating (i.e., heating tubes within ramp, etc.)

g. Other (please describe)

11. Other comments regarding wheelchair mobility during winter

Ramp Navigation Evaluation

1. Please rate the degree of difficult for ascending/climbing the three ramp slopes

Snow	**Very Easy**	**Easy**	**Moderate**	**Difficult**	**Extremely Difficult**
Steepest slope					
Middle slope					
Lowest slope					

Snow-ice	**Very Easy**	**Easy**	**Moderate**	**Difficult**	**Extremely Difficult**
Steepest slope					
Middle slope					
Lowest slope					

2. Please rate the degree of difficult for descending the three ramp slopes

Snow	**Very Easy**	**Easy**	**Moderate**	**Difficult**	**Extremely Difficult**
Steepest slope					
Middle slope					
Lowest slope					

Snow-ice	**Very Easy**	**Easy**	**Moderate**	**Difficult**	**Extremely Difficult**
Steepest slope					
Middle slope					
Lowest slope					

Wheelchair Ramp Study Data Sheet

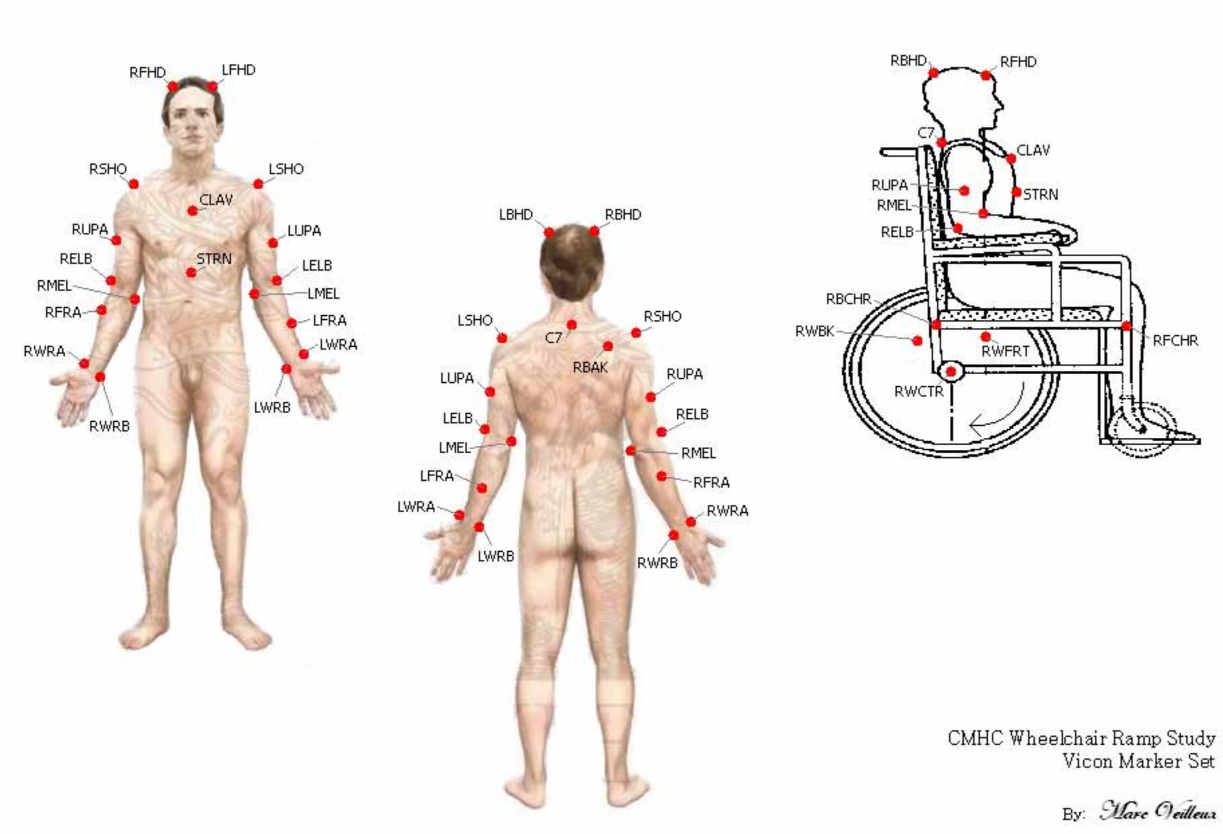
Subject Name	
Subject Number	
Date	
Mailing Address	

Measurements (cm)

Chair length	
Chair width	
Right upper arm	
Right lower arm	
Left upper arm	
Left lower arm	
Torso (shoulder to chair marker)	
Torso medial/lateral	

Wheelchair

Model	
Tire type	
Wheel diameter (inch)	
Comments	


RFHD
LFHD
RSHO
LSHO
CLAV
RUPA
LUPA
RELB
STRN
LELB
RMEL
LMEL
RFRA
LFRA
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RWRA
LWRB
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RBAK
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RWRB
RBHD
RFHD
C7
CLAV
RUPA
STRN
RMEL
RELB
RBCHR
RWBK
RWFRT
RFCHR
RWCTR
CMHC Wheelchair Ramp Study
Vicon Marker Set
By: Marc Veilleux

14. Appendix B – Consent Form, Information Sheet, and Subject Letter

The Ottawa Hospital | L'Hôpital d'Ottawa

Consent form for Research Study
"Effect of Snow and Ice on Exterior Ramp Navigation by Wheelchair Users"

Researcher Edward Lemaire, The Ottawa Hospital Rehabilitation Centre, 613-737-8899 ext.75592

I, _________________________, give consent to participate in this study where I will be asked to manually propel my wheelchair up and down a ramp that is covered with snow and snow-ice (ramp slopes of low (1:16), medium (1:12), high (1:10)).

I have received an information sheet about the study, have had its contents explained, and have been given a chance to ask any and all questions about the study.

I understand that:

- I will be seen by an occupational therapist, at The Ottawa Hospital Rehabilitation Centre, for approximately 30 minutes, to check my wheelchair and health status (on a day before the testing session). The occupational therapist can be consulted during or after the testing session.
- All testing will take place at the National Research Centre's Surface Transportation Technology (CSTT) climate engineering facility in Ottawa. Testing will take approximately 6 hours (3 hours per day for 2 days).
- Temperatures in the CSTT climate engineering facility will be -10° C to -15° C so winter clothing must be worn. I will be responsible for bringing winter clothing to the testing sessions.
- During testing, I will be asked to complete a questionnaire about my experiences using a wheelchair in winter.
- Reflective markers will be placed on my torso, arms, and wheelchair so that a video system can track my movements. A series of video cameras will record all trials. A safety-cord will be attached to my wheelchair that can be locked if I slip down the ramp or start moving at an uncomfortable speed (i.e., wheelchair can be stopped during ramp ascent or descent). Each day I will be asked to propel my wheelchair 5 times up and down three different ramp slopes.
- I will be asked to wear waist and chest straps to ensure that I do not fall forward if the ramp's safety stop is engaged.
- I may rest, or have a break, at any time in a warm room.
- I may refuse to ascend/climb or descend the ramp at any slope setting and at any time.
- By completing two testing sessions, I will receive $25.00 per day in compensation for my travel time and expenses.

- In the event that I withdraw from the study, none of my information will be used and all documents and information pertaining to my involvement in the study will be destroyed.
- The benefit of this research is to advance our understanding of wheelchair ramp use during winter.

I will be identified in this study only by an assigned code number. My anonymity will be maintained at all times, and only the investigator will keep a record of my name. The data will be stored in a locked file cabinet for ten years. Data will be destroyed after the ten year period. Data will be accessible by employees and students working at The Ottawa Hospital Rehabilitation Centre or OHRI employees with a research designation, however, any identifying will be removed so that no one knows which data belongs to me.

I will be advised of any new information that arises during the study that may have a bearing on my participation.

If I have any questions, or would like a copy of the study results, I can contact the researcher, Dr. Edward Lemaire, PhD, at 613-737-8899 x75592. For ethical issues, I can contact the Chair of the Research Ethics Board, Dr. Keith Wilson, at (613) 737-8899 ext. 75608 or via e-mail at kewilson@ottawahospital.on.ca.

I consent to having a **photograph** taken of me and having it published or presented for research and scientific purposes. yes____no_____ (please initial one)

I consent to having a **video** taken of me and having it published or presented for research and scientific purposes. yes_____no_____ (please initial one)

I understand the purpose of this study. By signing below, I agree to take part. This is assuming that

- **Information will be collected and used for research purposes only.**
- **This information will be kept private.**
- **There is no pressure on me to take part.**
- **Even if I do choose to take part now, I am still free to leave the study at any time and for any reason. I can to this by simply telling Dr. Lemaire .**
- **My decision – either to take part in the study or to leave the study – will have no effect on my treatment at the Ottawa Hospital Rehabilitation Centre, now or in the future.**
- **After signing, I will get a copy of this consent form and the information sheet for my records.**

I acknowledge that I have had the study and the contents of this consent form explained to me, that I understand this information and that I have received a copy of the consent form for my records.

Signed,

________________	__________	________________	__________
Participant	Date	Researcher/delegate	Date

________________	__________
Witness	Date

Project Summary

Winter is a defining season for Canadians. For people with disabilities, winter presents new obstacles for mobility and access to facilities. Wheelchair users are particularly affected by snow and ice conditions since previously accessible residences become inaccessible. Unfortunately, little research exists to make informed decisions regarding ramp design in winter. This study will perform the first biomechanical study of wheelchair mobility on ramps under snow and ice conditions.

Manual wheelchair users who typically self-propel their wheelchair in winter will be recruited through The Ottawa Hospital Rehabilitation Centre. An adjustable ramp will provide a safe testing environment at 1:10, 1:12, 1:16 slopes (i.e., wheelchair user will be safe if the chair slips during testing). The two test conditions are hard-packed snow and hard-packed snow with a "light freezing rain" and sand cover. Subjects will go up and down the ramp at each slope and at each condition. We will measure body and wheelchair motion to identify differences in wheelchair propulsion techniques, identify slippage and blockage events, and assess differences in ramp use strategies.

As the first biomechanical evaluation of wheelchair ramp navigation, this study will provide a better understanding of how wheelchair users deal with ramps in winter. In cases where the subjects cannot safely go up and down the ramp, such as at steeper slopes, we can determine what factors limit successful mobility. This study will help to define the best method for evaluating wheelchair mobility in winter.

The Ottawa Hospital | L'Hôpital d'Ottawa

Effect of Snow and Ice on Exterior Ramp Navigation by Wheelchair Users - Information Sheet

Winter is a defining season for Canadians. For people with disabilities, winter presents new obstacles for mobility and access to facilities. Wheelchair users are particularly affected by snow and ice conditions since previously accessible locations become inaccessible. This project is the first biomechanical study of wheelchair mobility on ramps under snow and ice conditions.

The research will provide a better understanding of how wheelchair users deal with ramps in winter. In cases where the subjects cannot safely climb or descend a ramp, such as at steeper slopes, we can define the factors that cause problems and suggest improvements.

Manual wheelchair users who typically self-propel their wheelchair in winter are being asked to participate in the study. A special, adjustable ramp (approximately 6 meters long and 1 meter wide) will be designed that provides a safe testing environment at low (1:16), medium (1:12), and high (1:10) slopes. Two tests will be evaluated, hard-packed snow and hard-packed snow with a "light freezing rain" and sand cover. Subjects will ascend and descend the ramp at each slope and at each condition. Body orientation information will be used to identify differences in wheelchair propulsion technique, wheel accelerations will identify slippage and blockage events, wheelchair information will identify ramp navigation variability (excessive side-to-side motion, etc.).

- Participants will be seen by an occupational therapist, at The Ottawa Hospital Rehabilitation Centre, for approximately 30 minutes on a day before the testing session (to check the participant's wheelchair). The occupational therapist can be consulted during or after the testing session. The occupational therapist will provide a business card with his or her contact information.
- All testing will take place at the National Research Centre's Surface Transportation Technology (CSTT) climate engineering facility in Ottawa. Testing will take approximately 6 hours (3 hours per day for 2 days). The distance from parking/drop-off to the testing room is approximately 25 m. Wheelchair accessible washrooms will be available on-site.
- Temperatures in the CSTT climate engineering facility will be -10° C to -15° C so winter clothing must be worn.

- The testing will involve:
    - Participants will be asked to complete a brief questionnaire about their experiences using a wheelchair in winter.
    - Reflective markers will be placed on the participant's torso, arms, and wheelchair so that a video system can track movement.
    - A safety-cord that can be locked if the chair slips down the ramp or moves at an uncomfortable speed will be attached to the wheelchair (i.e., wheelchair can be stopped at any time).
    - Participants will be asked to wear waist and chest straps to ensure that they do not fall forward if the ramps safety stop is engaged.
    - Subjects will ascend and descend the ramp at each slope and at each condition, starting with high (1:10), then medium (1:12), and finishing with low (1:16).
    - Subjects will rest between each section while the ramp slope is adjusted. You may stop for a rest at any point during testing.
    - After testing, each subject complete a series of questions related to the ramp trials.
- Participants may rest, or have a break, at any time. Time to rest in a warmer area will be provided. Hot beverages can be provided.
- Participants may also refuse to ascend/climb or descend the ramp at any slope setting and at any time.
- Washrooms at the facility are wheelchair accessible.
- Upon completion of 2 testing sessions participants will receive $25.00 per day in compensation for travel time and expenses.

Please contact Edward Lemaire, PhD, Project Primary Investigator, (613-737-8899 ext. 75592, elemaire@ottawahospital.on.ca) if you have questions about this study.

The Ottawa Hospital | L'Hôpital d'Ottawa

Request for Participation in a Research Study
"Effect of Snow and Ice on Exterior Ramp Navigation by Wheelchair Users"

Dear

Please consider this request to volunteer as a subject for the project "Effect of Snow and Ice on Exterior Ramp Navigation by Wheelchair Users". This is the first biomechanical study of wheelchair mobility on ramps under snow and ice conditions. This research will provide a better understanding of how wheelchair users deal with ramps in winter. Sometimes people cannot safely go up or down ramps in winter because the ramp is too steep, while this ramp was useful during dry summer days. We hope to understand the problems with ramp use in winter and use this information to suggest improvements to the building industry.

To participate in this study you must meet the following requirements:

- Manual wheelchair user who typically self-propels your wheelchair in winter
- Have no recent history of pressure sores
- Have no excessive shoulder inflammation
- Have no heart condition
- Have no problems with high blood pressure or history of uncontrolled autonomic dysreflexia

If you agree to participate in this study, you would be seen by an occupational therapist, at The Ottawa Hospital Rehabilitation Centre, for approximately 30 minutes on a day before the testing session to check your wheelchair and verify that you do not have any physical issues that can be a problem during testing. The occupational therapist would be available for consultation during or after the testing session. The occupational therapist would provide you with a business card with his or her contact information.

All testing will take place at the National Research Centre's Surface Transportation Technology (CSTT) climate engineering facility in Ottawa (near the airport). Testing will take approximately 6 hours (3 hours per day for 2 days). The distance from parking/drop-off to the testing room is approximately 25 m. Wheelchair accessible washrooms will be available on-site. Temperatures in the CSTT climate engineering facility will be -10° C to -15° C so winter clothing must be worn.

During the study you would be asked to ascend (go up) and descend (go down) a special, adjustable ramp (approximately 6 meters long and 1 meters wide) that provides a safe testing environment at low, medium, and high slopes. Two tests will be evaluated, hard-packed snow and hard-packed snow with a "light freezing rain" and sand cover. You would be asked to ascend and descend the ramp at each slope and in each condition. Body orientation information will be used to identify differences in wheelchair technique, wheel accelerations will identify slippage and blockage events, wheelchair information will identify ramp navigation patterns (excessive side-to-side motion, etc.).

The testing involves:

- Completing a brief questionnaire about your experiences using a wheelchair in winter
- Placing reflective markers on your torso, arms, and wheelchair so that a video system can track your movements.
- Attaching a safety-cord that can be locked if the chair slips down the ramp, or moves at an uncomfortable speed, is attached to your wheelchair (i.e., wheelchair can be stopped at any time).
- Wearing waist and chest straps to ensure that you do not fall forward if the ramp's safety stop is engaged.
- Ascending and descending the ramp at each slope and at each condition, starting with high, then medium, and finishing with low
- Completing a series of questions related to the ramp trials

You would be able to rest between each session, while the ramp slope is adjusted. You would be able to rest, or have a break, at any time. A warm rest area and hot beverages will be provided. You may refuse to ascend or descend the ramp for any slope setting and at any time. Upon completion of each testing session, you will receive $25.00 per day in compensation for travel time and expenses.

Please contact Cynthia Kendell, Project Assistant to either indicate your interest as a subject for this research project or to tell us that you do not want to be contacted further about this project:

- Phone: 613-737-8899, extension 75326
- Email: ckendell@ottawahospital.on.ca

You will be contacted by telephone within the next four weeks if we do not receive a reply from you.

You can also contact Edward Lemaire, PhD, Project Primary Investigator, (613-737-8899, ext. 75592, elemaire@ottawahospital.on.ca) if you have questions about this study.

Thank you for considering this request. We look forward to working with you on this project.

Yours truly,

Marcel M. Desrosiers, M.A.; OT(C); OT Reg. (ONT)

The Ottawa Hospital | L'Hôpital d'Ottawa

Formulaire de consentement
Étude : « L'effet de la neige et de la glace sur le déplacement en fauteuil roulant sur les rampes d'accès extérieures »

Chercheur : Edward Lemaire, Centre de réadaptation de L'Hôpital d'Ottawa
613-737-8899, poste 75592

Je, ________________________, accepte de participer à une étude où on va me demander de monter et de descendre une rampe d'accès en fauteuil roulant. Cette rampe d'accès sera couverte de neige dans un cas et sera couverte de neige et de glace dans l'autre cas. L'inclinaison de la rampe d'accès sera faible (1:16), moyenne (1:12) et élevée (1:10).

J'ai reçu la feuille d'information sur l'étude et on m'a expliqué le contenu. On m'a aussi donné l'occasion de poser mes questions au sujet de l'étude.

Je comprends ce qui suit :

- Je vais rencontrer un ergothérapeute au Centre de réadaptation de L'Hôpital d'Ottawa pendant environ 30 minutes. Le but de cette rencontre est de vérifier mon fauteuil roulant et mon état de santé. Cette rencontre n'aura pas lieu la même journée que la séance d'évaluation. Je pourrai consulter l'ergothérapeute pendant ou après la séance d'évaluation.
- L'évaluation au complet aura lieu à l'installation d'ingénierie climatique du Centre de technologie des transports de surface (CTTS). Ce centre fait partie du Conseil national de recherches du Canada à Ottawa. Les tests nécessiteront environ 6 heures (2 journées de 3 heures chacune).
- La température à l'installation d'ingénierie climatique du CTTS sera entre -10 °C et -15 °C. Je devrai donc porter des vêtements d'hiver. Je suis responsable d'apporter des vêtements d'hiver aux séances d'évaluation.
- Pendant l'évaluation, je devrai remplir un questionnaire sur mes expériences en fauteuil roulant l'hiver.
- Des marqueurs réfléchissants seront placés sur mon torse, mes bras et mon fauteuil roulant pour permettre à un système vidéo de suivre mes mouvements. Une série de caméras vidéo vont enregistrer tous les essais. Un câble de sécurité sera attaché à mon fauteuil roulant pour permettre le blocage du mécanisme si je commence à glisser ou à avancer à une vitesse non confortable. En d'autres mots, il sera possible d'arrêter le fauteuil roulant pendant que je monte ou que je descends la rampe d'accès. À chacune des 2 journées, je devrai monter et descendre 5 fois la rampe d'accès et celle-ci sera installée selon 3 pentes (inclinaisons) différentes.

- On va me demander de porter une sangle (attache) à la taille et au thorax. Ces attaches empêcheront que je tombe en avant si on déclenche le mécanisme d'arrêt de sécurité de la rampe d'accès.
- Je pourrai me reposer ou prendre une pause n'importe quand dans une salle réchauffée.
- Je pourrai refuser de monter ou de descendre la rampe d'accès à n'importe quelle inclinaison et en tout temps si je veux.
- Pour les 2 séances d'évaluation, on me remettra 25 $ par jour afin de compenser mes frais et dépenses de déplacement.
- Si je me retire de l'étude, aucun de mes renseignements personnels ne seront utilisés et tous les renseignements et documents liés à ma participation seront éliminés.
- Le but de cette recherche est de mieux comprendre l'utilisation des rampes d'accès pour fauteuils roulants l'hiver.

Je serai identifié dans cette étude seulement par un code numérique assigné. Mon anonymat sera maintenu en tout temps et seul le chercheur pourra garder un dossier avec mon nom. Les données de l'étude seront conservées dans un classeur verrouillé pendant 10 ans. Après la période de 10 ans, les données seront détruites. Les employés et les étudiants travaillant au Centre de réadaptation de L'Hôpital d'Ottawa ou les chercheurs de l'Institut de recherche en santé d'Ottawa (IRSO) auront accès à ces données. Par contre, toute l'information permettant de m'identifier sera enlevée des données pour éviter qu'on sache quelles données sont les miennes.

Je serai informé de tout nouveau renseignement qui deviendra disponible pendant le déroulement de l'étude et qui pourrait influencer ma décision de continuer à participer à l'étude.

Si j'ai des questions, ou si j'aimerais avoir une copie des résultats de l'étude, je peux communiquer avec le Dr. Edward Lemaire, Ph.D., 613-737-8899, poste 75592. Si j'ai des questions concernant la conduite éthique de cette étude, je peux communiquer avec le Dr. Keith Wilson, président du Comité d'éthique de la recherche, par téléphone au numéro 613-737-8899, poste 75608, ou par courriel à l'adresse kewilson@ottawahospital.on.ca.

J'accepte qu'on prenne une **photo** de moi et qu'on la publie ou qu'on la présente à des fins scientifiques ou aux fins de la recherche. Oui ____ Non_____ (Mettez vos initiales à côté de votre réponse.)

J'accepte qu'on prenne une **vidéo** de moi et qu'on la publie ou qu'on la présente à des fins scientifiques ou aux fins de la recherche. Oui _____ Non_____ (Mettez vos initiales à côté de votre réponse.)

Je comprends le but de cette étude. En signant ci-dessous, j'accepte de participer. Cela à la condition que :

- **L'information sera recueillie et utilisée pour la recherche seulement.**
- **L'information sera gardée confidentielle.**
- **On ne mettra pas de pression sur moi pour que je participe.**
- **Même si je décide maintenant que je veux participer, je peux plus tard changer d'idée et quitter l'étude n'importe quand et pour n'importe quelle raison. Il me suffira de le dire au D^r^ Lemaire.**
- **Ma décision de participer à l'étude ou de quitter l'étude n'aura aucune influence sur mon traitement au Centre de réadaptation de L'Hôpital d'Ottawa, maintenant ou à l'avenir.**
- **Après avoir signé, on me remettra une copie de ce formulaire de consentement et de la feuille d'information pour mes dossiers personnels.**

Je reconnais qu'on m'a expliqué cette étude et le contenu de cette feuille d'information, que je comprends cette information et que j'ai reçu une copie du formulaire de consentement pour mes dossiers.

Signature :

____________________	___________	____________________	___________
Participant	Date	Chercheur /délégué	Date
____________________	___________		
Témoin	Date		

Résumé du projet

L'hiver est un symbole du Canada. Pour les personnes handicapées, l'hiver présente de nouveaux obstacles pour la mobilité et l'accès aux installations. Les conditions enneigées ou glacées affectent en particulier les utilisateurs de fauteuil roulant en empêchant l'accès à des lieux auparavant accessibles. Malheureusement, il y a eu peu de recherches qui ont été faites jusqu'à maintenant pour éclairer les décisions sur la conception des rampes d'accès pour fauteuils roulants l'hiver. Avec ce projet, nous allons mener la première étude biomécanique sur la mobilité en fauteuil roulant sur les rampes d'accès enneigées et glacées.

Le Centre de réadaptation de L'Hôpital d'Ottawa recrutera des utilisateurs de fauteuil roulant manuel qui typiquement manœuvrent eux-mêmes leur fauteuil l'hiver pour participer à cette étude. On utilisera une rampe ajustable pour tester en toute sécurité la manœuvrabilité en fauteuil roulant à des pentes réglées à 1:10, 1:12 et 1:16. En d'autres mots, il n'y aura pas de danger pour l'utilisateur si le fauteuil glisse pendant les essais. Il y a aura 2 essais. Le premier sera une rampe d'accès couverte de neige compacte et le deuxième essai sera une rampe d'accès couverte de neige compacte, de « pluie verglaçante légère » et de sable. Les participants devront monter et descendre la rampe à chaque inclinaison et dans chaque condition climatique. L'équipe de recherche mesurera les mouvements du corps et du fauteuil roulant afin d'identifier les différences de techniques de propulsion du fauteuil, les événements de glissement et de blocage et les différences de stratégies d'utilisation des rampes d'accès.

Cette première évaluation biomécanique sur l'utilisation des rampes d'accès nous permettra de mieux comprendre comment les utilisateurs de fauteuil roulant composent avec les rampes d'accès l'hiver. Dans les situations où les participants ne pourront pas monter ou descendre la rampe d'accès en toute sécurité, par exemple si la pente est trop raide, nous déterminerons les facteurs qui limitent la mobilité. Cette étude aidera à définir la meilleure méthode pour évaluer la mobilité en fauteuil roulant l'hiver.

Feuille d'information
« L'effet de la neige et de la glace sur le déplacement en fauteuil roulant sur les rampes d'accès extérieures »

L'hiver est un symbole du Canada. Pour les personnes handicapées, l'hiver présente de nouveaux obstacles à la mobilité et à l'accès aux installations. Les utilisateurs de fauteuil roulant sont particulièrement affectés par les conditions enneigées ou glacées car ces conditions empêchent l'accès à des lieux auparavant accessibles. Ce projet est la première étude biomécanique sur la mobilité en fauteuil roulant sur les rampes enneigées et glacées.

Cette recherche nous permettra de mieux comprendre comment les utilisateurs de fauteuil roulant composent avec les rampes d'accès l'hiver. Dans les situations où les participants ne pourront pas monter ou descendre une rampe d'accès en toute sécurité, par exemple une rampe plus raide, nous pourrons définir les facteurs qui causent des problèmes et suggérer des améliorations.

Nous invitons les utilisateurs de fauteuil roulant manuel qui typiquement se déplacent eux-mêmes en fauteuil l'hiver à participer à cette étude. Une rampe d'accès spéciale et ajustable (d'environ 6 mètres de longueur et 1 mètre de largeur) sera conçue. La pente de cette rampe pourra être ajustée pour des essais sans danger aux niveaux suivants : faible pente (1:16), pente moyenne (1:12) et pente élevée (1:10). On fera 2 essais, le premier dans des conditions de neige compacte et le deuxième dans des conditions de neige compacte avec une « pluie verglaçante légère » et une couche de sable. Les participants devront monter et descendre la rampe dans les 2 conditions climatiques. L'information sur l'orientation du corps permettra d'identifier les différences dans la technique de propulsion du fauteuil roulant. L'accélération des roues permettra d'identifier les événements de glissement et de blocage. L'information liée au fauteuil roulant identifiera la variabilité de maniabilité de la rampe (mouvement de roulis excessif, etc.).

- Avant la séance d'évaluation, les participants devront rencontrer un ergothérapeute au Centre de réadaptation de L'Hôpital d'Ottawa pour faire vérifier leur fauteuil roulant. Cette rencontre durera environ 30 minutes. Les participants pourront consulter l'ergothérapeute pendant ou après la séance d'évaluation. L'ergothérapeute remettra sa carte d'affaires indiquant ses coordonnées aux participants.
- Tous les tests auront lieu à l'installation d'ingénierie climatique du Centre de technologie des transports de surface (CTTS) à Ottawa. Ce centre fait partie du Conseil national de recherches du Canada. Les tests nécessiteront environ 6 heures (2 journées de 3 heures chacune). Il y a environ 25 mètres qui sépare le stationnement ou l'endroit où l'on vous déposera et la salle des tests. Des

toilettes accessibles en fauteuil roulant sont disponibles sur place.

- La température dans l'installation d'ingénierie climatique du CTTS est entre -10 °C et -15 °C. Il est donc essentiel de porter des vêtements d'hiver.
- Voici ce que les tests comprennent :
    - Les participants devront remplir un petit questionnaire sur leurs expériences avec le fauteuil roulant l'hiver.
    - On appliquera des marqueurs réfléchissants sur le torse, les bras et sur le fauteuil roulant du participant pour permettre à un système vidéo de suivre ses mouvements.
    - On attachera un câble de sécurité au fauteuil roulant pour nous permettre de l'arrêter en tout temps au cas où il glisserait de la rampe d'accès ou avancerait à une vitesse non confortable.
    - Les participants porteront des attaches (sangles) à la taille et à la poitrine pour éviter de tomber en avant si le mécanisme d'arrêt de la rampe d'accès est déclenché.
    - Les participants devront monter et descendre la rampe d'accès dans les 2 situations climatiques différentes en commençant par la pente élevée (1 :10), ensuite la pente moyenne (1 :12) et enfin, la faible pente (1 :16).
    - Les participants se reposeront entre chaque section pendant qu'on ajuste la rampe. Ils pourront arrêter n'importe quand pendant l'évaluation pour se reposer.
    - Après l'évaluation, chaque participant devra répondre à une série de questions sur les essais qu'on lui a fait faire sur la rampe d'accès.
- Les participants pourront se reposer ou prendre une pause n'importe quand dans une salle réchauffée. Des boissons chaudes seront disponibles.
- Les participants pourront refuser de monter ou de descendre la rampe d'accès pour n'importe quelle inclinaison/pente et en tout temps.
- Les toilettes de l'installation sont accessibles en fauteuil roulant.
- À la fin des 2 séances d'évaluation, les participants recevront 25 $ par jour en échange de leur temps et de leurs dépenses de déplacement.

Veuillez communiquer avec Edward Lemaire, Ph.D., chercheur principal du projet, au 613-737-8899, poste 75592, ou par courriel à elemaire@ottawahospital.on.ca si vous avez des questions au sujet de cette étude.

The Ottawa Hospital | L'Hôpital d'Ottawa

Invitation à participer à une étude de recherche intitulée « L'effet de la neige et de la glace sur le déplacement en fauteuil roulant sur les rampes d'accès extérieures »

Madame,
Monsieur,

Nous vous invitons à participer volontairement à un projet de recherche intitulé « L'effet de la neige et de la glace sur le déplacement en fauteuil roulant sur les rampes d'accès extérieures ». Il s'agit de la première étude biomécanique sur la mobilité en fauteuil roulant sur des rampes d'accès glacées et enneigées. Cette recherche nous aidera à mieux comprendre comment les utilisateurs de fauteuil roulant manœuvrent sur les rampes d'accès l'hiver. L'hiver, il arrive que les personnes ne soient pas capables de monter ou de descendre les rampes d'accès, en toute sécurité, parce que qu'elles sont trop en pente raide alors que pendant les journées d'été sans pluie, ces rampes étaient utiles. Nous espérons recueillir de l'information sur les problèmes d'utilisation des rampes d'accès l'hiver afin de suggérer des améliorations à l'industrie de la construction.

Voici les critères pour participer à cette étude :

- Vous êtes un utilisateur de fauteuil roulant manuel et typiquement, vous conduisez vous-même votre fauteuil roulant l'hiver.
- Vous n'avez pas d'antécédents récents de plaies de pression.
- Vous n'avez aucune inflammation excessive des épaules.
- Vous n'avez pas de maladie du cœur.
- Vous n'avez pas de problèmes d'hypertension artérielle ou d'antécédents de dysréflexie autonome non contrôlée.

Si vous acceptez de participer à cette étude, vous commencerez par voir un ergothérapeute au Centre de réadaptation de L'Hôpital d'Ottawa. Le rendez-vous durera environ 30 minutes et aura lieu avant la séance d'évaluation, mais pas le même jour. L'ergothérapeute vérifiera votre fauteuil roulant et s'assurera que vous n'avez pas de difficultés physiques qui pourraient poser un problème pendant l'évaluation. L'ergothérapeute sera disponible pendant ou après la séance d'évaluation et vous pourrez le consulter. Il vous fournira sa carte d'affaires avec ses coordonnées.

Tous les tests auront lieu à l'installation d'ingénierie climatique du Centre de technologie des transports de surface (CTTS) à Ottawa (situé près de l'aéroport). Ce centre fait partie du Conseil national de recherches du Canada. Les tests nécessiteront environ 6 heures (2 journées de 3 heures chacune). Entre le stationnement ou l'endroit où on vous déposera et la salle des tests, il y a une distance d'environ 25 mètres. Des toilettes accessibles en fauteuil roulant sont disponibles sur place. La température dans l'installation d'ingénierie climatique du CTTS est entre -10 °C et -15 °C. Il est donc essentiel de porter des vêtements d'hiver.

Pendant l'étude, on vous demandera de monter et de descendre une rampe d'accès spéciale et ajustable d'environ 6 mètres de longueur et 1 mètre de largeur. Cette rampe d'accès spéciale offre un environnement sécuritaire pour tester des pentes (inclinaisons) faibles, moyennes et élevées. Il y aura 2 tests. Lors du premier test, la pente sera couverte de neige compacte. Lors du deuxième test, elle sera couverte de neige compacte avec une « pluie verglaçante légère » et une couverture de sable. Vous devrez monter et descendre la rampe d'accès dans les 2 conditions décrites. Pour identifier les différences dans la technique de fauteuil roulant, on recueillera de l'information sur l'orientation du corps. Pour identifier les situations de glissement et de blocage, on observera l'accélération des roues. Pour obtenir de l'information sur le type de navigation de la rampe d'accès (roulis excessif, etc.), on recueillera de l'information sur le fauteuil roulant.

Les tests comprennent :

- Vous devrez remplir un petit questionnaire sur vos expériences avec le fauteuil roulant l'hiver.
- On appliquera des marqueurs réfléchissants sur votre torse, vos bras et sur votre fauteuil roulant pour permettre à un système vidéo de suivre vos mouvements.
- On attachera un câble de sécurité à votre fauteuil roulant pour nous permettre de l'arrêter en tout temps au cas où il glisserait de la rampe d'accès ou avancerait à une vitesse non confortable.
- Vous porterez des attaches à la ceinture et à la poitrine pour éviter que vous tombiez en avant si on déclenche le mécanisme d'arrêt de la rampe d'accès.
- Vous devrez monter et descendre la rampe d'accès dans les 2 situations différentes et en commençant par la pente (inclinaison) élevée, ensuite la pente moyenne et enfin, la pente la plus faible.
- Vous devrez répondre à une série de questions sur les tests qu'on vous aura fait faire sur la rampe d'accès.

Vous pourrez vous reposer entre chaque séance pendant qu'on ajuste l'inclinaison de la rampe d'accès. Vous pourrez également vous reposer ou prendre une pause n'importe quand. Un endroit de repos bien au chaud sera disponible ainsi que des boissons chaudes. Si vous voulez, vous pourrez refuser de monter ou de descendre la rampe d'accès pour n'importe quelle inclinaison et en tout temps. À la fin de chaque séance d'évaluation, nous vous remettrons 25 $ pour vos frais et votre temps de déplacement.

Si vous êtes intéressé à participer à ce projet de recherche ou si vous ne voulez plus qu'on communique avec vous concernant ce projet, communiquez avec Cynthia Kendell, adjointe au projet :

- Téléphone : 613-737-8899, poste 75326
- Courriel : ckendell@ottawahospital.on.ca

Nous vous appellerons si nous ne recevons pas de réponse de votre part d'ici les 4 prochaines semaines.

Vous pouvez également communiquer avec Edward Lemaire, Ph.D., chercheur principal du projet (613-737-8899, poste 75592, elemaire@ottawahospital.on.ca) si vous avez des questions au sujet de cette étude.

Merci d'envisager de participer. Nous avons hâte de travailler avec vous à ce projet.

Marcel M. Desrosiers, M.A., OT(C), OT Reg. (ONT)

Filename: Wheelchair Winter final-report-Jan-19-2010.docx
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Title: Effect of Snow and Ice on Exterior Ramp Navigation by Wheelchair Users
Subject:
Author: elemaire
Keywords:
Comments:
Creation Date: 4/6/2010 10:53:00 AM
Change Number: 2
Last Saved On: 4/6/2010 10:53:00 AM
Last Saved By: Karen Marcus
Total Editing Time: 3 Minutes
Last Printed On: 4/8/2010 10:41:00 AM
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Number of Pages: 78
Number of Words: 17,543 (approx.)
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