



Systematic Review

Winter Mobility and Community Participation Among People Who Use Mobility Devices: A Scoping Review



Jacque Ripat, PhD ^a, Kathryn M. Sibley, PhD ^{b,c},
Ed Giesbrecht, PhD ^a, Brittany Curtis, MCP ^a,
Alexie Touchette, BA ^b, Jaimie Borisoff, PhD ^{d,e},
Karen Ethans, MD, FRCPC ^f, Yue Li, PhD ^g,
Ernesto Morales, PhD ^h

^a Department of Occupational Therapy, University of Manitoba, Winnipeg, Manitoba, Canada

^b Department of Community Health Sciences, University of Manitoba, Winnipeg, Manitoba, Canada

^c Centre for Healthcare Innovation, University of Manitoba, Winnipeg, Manitoba, Canada

^d Rehabilitation Engineering Design Laboratory, British Columbia Institute of Technology, Burnaby, British Columbia, Canada

^e International Collaboration on Repair Discoveries (ICORD), University of British Columbia, Vancouver, British Columbia, Canada

^f Department of Medicine, University of Manitoba, Winnipeg, Manitoba, Canada

^g KITE, Toronto Rehabilitation Institute - University Health Network, Toronto, Ontario, Canada

^h Department of Rehabilitation, Université Laval, Québec City, Québec, Canada

KEYWORDS

Cold climate;
Community participation;
Rehabilitation;
Self-help devices;
Wheelchairs

Abstract Objective: To identify the knowledge, products, and strategies for individuals with mobility-related disabilities used to address challenging winter conditions.

Data Sources: AgeLine, OVID, Scopus, and CIHAHL were searched for studies that met the inclusion criteria, from inception to April 2018. Sources for gray literature, or information outside commercial publishing, included ProQUEST, government websites, and manufacturers, vendors, and consumer organization websites.

Source Selection: Population of people with limited or reduced mobility or mobility device users involved in winter-related environmental conditions; aim was to increase activity, participation, or safety.

Data Extraction: Two reviewers independently applied the inclusion criteria to select eligible sources. Two reviewers independently extracted the data from each source.

List of abbreviations: ICF, International Classification of Functioning, Disability and Health.

Supported by the University Collaborative Research Grant, University of Manitoba (grant no. #47138).

Disclosures: none

Presented to the Rehabilitation Engineering and Assistive Technology Society of North America, July 13, 2018, Washington, DC.

Cite this article as: Arch Rehabil Res Clin Transl. 2020;2:100018.

<https://doi.org/10.1016/j.arrct.2019.100018>

2590-1095/© 2019 The Authors. Published by Elsevier Inc. on behalf of the American Congress of Rehabilitation Medicine. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Data Synthesis: Twenty-three published peer-reviewed papers were located. Study populations were predominantly those who used wheelchairs (mixed wheelchair type, n=7; power, n=4; manual, n=2), canes (n=3), or specialized winter footwear (n=2). The primary focus of these papers was determined to be tool or device (n=10), recommendations (n=9), strategy (n=2), or resource (n=2). Civic policy documents were variable in citizen responsibility for snow clearing. Limited winter-related supports were identified on consumer organization websites. Although some winter-specific products exist, very few studies have examined the effectiveness of any of these products.

Conclusions: Despite the common experience of challenging winter conditions, a paucity of winter-specific research and innovation relevant for individuals who use mobility devices exists. Researchers, consumers, and industry need to partner to develop novel tools, strategies, resources, and evidence-based recommendations.

© 2019 The Authors. Published by Elsevier Inc. on behalf of the American Congress of Rehabilitation Medicine. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

In many parts of the world, winter is characterized by below-freezing temperatures, high accumulations of snow and ice, and strong winds. These conditions can create challenges to community participation (eg, access to community spaces, engagement in community-based activities, and involvement in social relations)¹ for all citizens living in these regions. For people who report a mobility-related disability, many of whom use a mobility device such as a cane, walker, or wheelchair, these challenges may be magnified: mobility device wheels may become stuck or fail to gain traction on snow or ice^{2,3}; ice- or snow-covered outdoor ramps, sidewalks, and roads may make mobility difficult or unsafe²⁻⁶; individuals may experience thermal hand injuries (ie, frostbite) from having to push or steer mobility devices; and diminished battery capacity of powered devices in cold temperatures may restrict range of mobility.⁶ These factors often limit community participation among people with mobility-related disabilities during winter months.^{1,3-7} In a survey of 99 wheelchair users in Manitoba, Canada, where the average winter temperature is below 0°C and average snowfall is 113.7 cm,⁸ 44% identified going outdoors only 1-2 times per week or less in the winter months, compared to 7% who reported the same frequency in the summer months.³ Another study reported increased feelings of loneliness resulting from reduced outdoor mobility in winter.⁹ Work by the current authors reinforced this evidence and pointed to additional issues related to policy gaps (eg, snow clearance, transportation options).⁷

In light of the many winter-related challenges among mobility device users and the detrimental effect of limited community participation on health and well-being, there is a need to identify strategies that address these issues.^{1,3,9} The aim of this study was to conduct a scoping review of the literature to identify existing knowledge as well as information available about products and strategies for people who use mobility devices in the winter. The findings from this review will contribute to development of a web-based *Winter Toolkit* of accessibility solutions (knowledge, products, resources) for individuals who use mobility devices, as well as other stakeholders including clinicians, representatives of organizations that support individuals with disabilities, and researchers interested in this area.

Methods

Because of the exploratory nature of the present study, a scoping review was conducted. Scoping reviews are a rigorous method of knowledge synthesis that serve to “map evidence on a topic and identify main concepts, theories, sources, and knowledge gaps.”^{10(p467)} Anticipating a dearth of research on this topic, we identified gray literature as an additional source of important information. Gray literature refers to material delivered outside of traditional or commercial publishing sources (ie, self-published) and may not be peer reviewed.¹¹ We were particularly interested in user-generated web content such as online forums, non-peer-reviewed sources, conference proceedings, dissertations and theses, and government documents.

We used the scoping review framework described by Arksey and O’Malley¹² and expanded on by others.¹³ Each of the 5 steps and their associated actions are outlined below.

1. Identify the research question: Our multidisciplinary team, consisting of researchers with backgrounds in occupational therapy, knowledge translation, rehabilitation engineering, architecture, and psychiatry engaged in a series of discussions to develop the guiding research question for this study: What are the tools, strategies, resources, and recommendations that have been shown to facilitate winter community participation for people who use mobility devices?

2. Identifying relevant studies and content: Searches of both peer-reviewed and gray literature were conducted. Peer-reviewed literature databases searched were AgeLine, MEDLINE, Scopus, and CIHAHL. In consultation with a health sciences bibliographer, a search strategy was developed for each database, using conventions unique to each database ([appendix 1](#) for sample search strategy). We reviewed all study designs, including both quantitative and qualitative data, published from inception to April 2018. Reference lists of selected papers were also reviewed to identify potential sources. References were uploaded and managed using EndNote Online.

A comprehensive gray literature search was also conducted. An initial list was generated based on the research

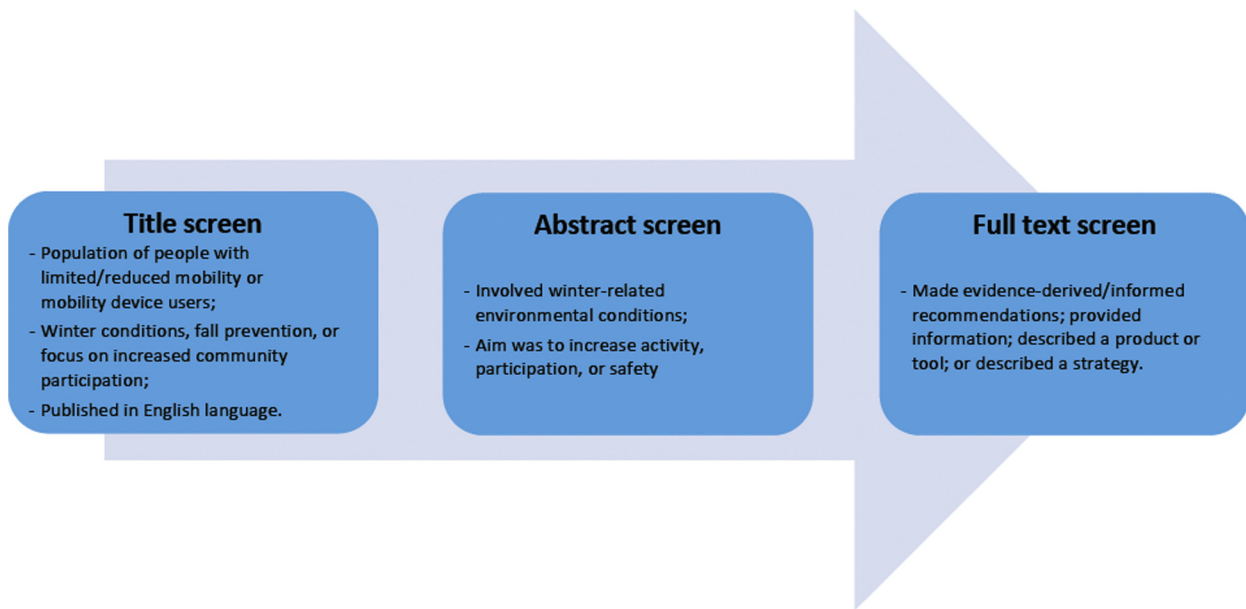


Fig 1 Selection process for peer-reviewed literature.

teams' experience and knowledge. Sources included thesis and dissertations, conference proceedings, Government of Canada publications, provincial health documents, civic policy documents related to snow-clearing policy and accessible public transportation from 18 Canadian cities (13 provincial capitals and 5 additional larger urban centers), organizations known to provide supports or services to mobility device users, assistive devices vendor or manufacturer websites, and google search for winter-relevant assistive devices. The list was circulated several times among team members for review, seeking additions and suggestions. Search terms specific to each source were generated through consultation with a health science bibliographer and search information provided on individual sites. The gray literature sources searched, search strategy, review, and extraction process relevant to each source type is shown in [appendix 2](#).

3. Selecting content: For peer-reviewed literature, 3 rounds of review were conducted (title screen, abstract screen, full-text screen) with inclusion criteria outlined for each round ([fig 1](#)).

Studies were excluded if they did not address people with limited mobility or use of mobility aids; the study participant was a caregiver; research centered on biomechanical characteristics of slips and falls without recommendations for prevention; research focused on winter health risks unrelated to mobility; gaps in fall prevention literature were highlighted, but not directly addressed; areas for relevant research were suggested, but not explored; the research focused solely on the mechanics of equipment without consideration of use; the focus was on adaptive winter sports for professional athletes; or the focus was on indoor fall prevention.

Two authors (A.T. and B.C.) independently applied the inclusion criteria at each round. If there was a lack of

agreement in the title and abstract screen, we erred on the side of inclusion and carried the study forward into the subsequent round. The first author (J.R.) addressed any lack of agreement between reviewers in the final round. Gray literature was retrieved by A.T. or B.C. via the search strategy outlined for each source; the first author confirmed inclusion based on the study aim.

4. Charting data: For each source the author, title, year published, country of origin, study aim, study design, study population, and outcomes or recommendations were charted in an Excel spreadsheet. A process for ensuring consistency of data extraction was enacted, with 1 research assistant extracting all data and a second research assistant extracting data from a subsample ($n=5$) of the selected articles. The extractions were compared and confirmed by the first author and extraction processes clarified as needed.

5. Collating, summarizing, and reporting results: Three authors (J.R., K.M.S., E.G.) were engaged in a process of collating and summarizing the results. To ensure consistency of data extraction, 2 team members independently extracted the data from each source and results were compared. In situations where there was a lack of agreement, the article was sent to the third team member for independent review and a final determination made by the first author. Each article was coded on 3 constructs. First, each source was categorized as primarily focused on a *tool* (device or technology), *strategy* (use of a device, or teaching people a method), *resource* (information gathering or sharing), or *recommendation* (suggestion for improving winter mobility and/or participation). Second, the primary domain of interest in each source was identified as *body functions and-structures*, *activities*, *participation*, or *environmental factors* as outlined in the International Classification of

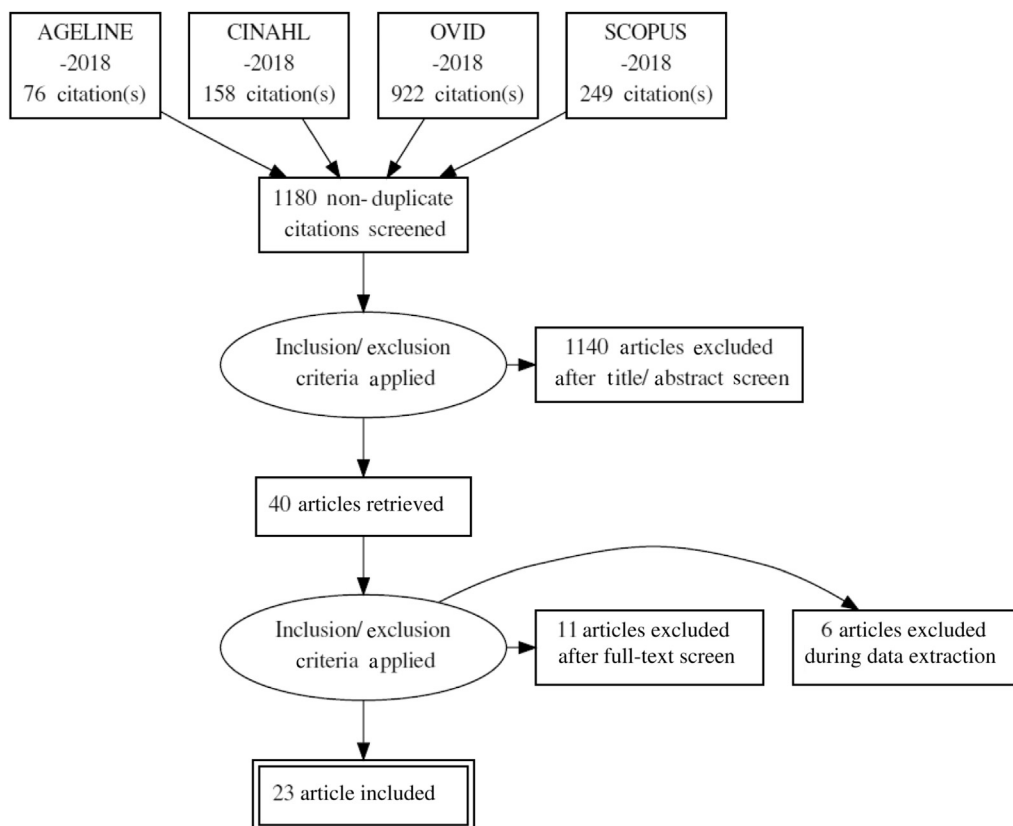


Fig 2 Diagram of study selection.

Functioning, Disability and Health.¹⁴ Finally, if the domain was deemed to be an environmental factor, this was further subcategorized as addressing 1 of the 5 types of environmental factors as outlined in the ICF: “products and technology; natural environment and human made changes to the environment; support and relations; attitudes; or services, systems, and policies.”^{15(p591)} After all charting, collating, and summarizing activities were complete, the research team engaged in several in-person and online dialogues, looking for patterns and themes within the charted data.

Results

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) diagram depicting the peer-reviewed article selection process is shown in figure 2. The initial search resulted in 1403 articles (AgeLine, $n=76$; CINAHL, $n=156$; MEDLINE, $n=922$; Scopus, $n=249$). After deleting duplicates, 1180 potentially eligible articles remained. After round 1 exclusions, 109 articles remained; round 2 exclusions reduced this number to 40; and after round 3 exclusions, 23 papers were included in the review. Table 1 lists the peer-reviewed studies included.

Summary of peer-reviewed studies

Most of the 23 studies were conducted in Canada ($n=14$) or the United States ($n=5$); 3 studies were conducted in Japan

and 1 study in Denmark. Study designs included cross-sectional ($n=8$), qualitative methods ($n=5$), mixed methods ($n=3$), product or simulation testing ($n=2$), pre-post design ($n=2$), case study ($n=2$), and prospective randomized trial ($n=1$). Study populations were predominantly those who used wheelchairs (mixed wheelchair type, $n=7$; power, $n=4$; manual, $n=2$; gel cushions on wheelchair, $n=1$), canes ($n=3$), specialized winter footwear ($n=2$), or no device specified ($n=4$). The primary focus of the paper (fig 3) was determined to be tool or device ($n=10$), recommendations ($n=9$), strategy ($n=2$), or resource ($n=2$). The primary ICF domain addressed in each of the studies (fig 4) was environment ($n=14$), participation ($n=5$), activity ($n=2$), and body structure or function ($n=2$). Among the 14 studies whose focus was on environmental factors, 10 addressed products and technology; 2 addressed services, systems, and policies; 1 focused on the natural environment and human-made changes, and 1 addressed several factors (products and technology; support and relations; attitudes; services, systems, policies).

Summary of gray literature

Table 2 provides a summary of the gray literature search and collating or summarizing results.

Five theses or dissertations were located that focused on aspects of winter accessibility; all were completed by students in Canadian universities. Three of the 5 focused on tools or devices and addressed environmental factors (products and technology).³⁴⁻³⁶ Two aimed to provide

Table 1 Table of included peer-reviewed studies

Author	Article Title	Tool, Strategy, Resource, or Recommendation	Primary ICF Domain	Environmental Factor
Lemaire et al ²	Wheelchair ramp navigation in snow and ice-grit conditions	Recommendations	Environment	Products and technology
Ripat et al ³	Barriers to wheelchair use in the winter	Recommendations	Environment	Products and technology support and relations; attitudes; services, systems, and policies
Li et al ⁴	Aging and the use of pedestrian facilities in winter—the need for improved design and better technology	Recommendations	Environment	Natural environment and human-made changes to the environment
Lindsay et al ⁵	Weather, disability vulnerability, and resilience: exploring how youth with physical disabilities experience winter	Recommendations	Participation	
Ripat et al ⁷	Patterns of community participation across the seasons: a year-long case study of three Canadian wheelchair users	Strategy	Environment	Services, systems, and policies
Berthelette et al ¹⁶	Assessing manual wheelchair caster design for mobility in winter conditions	Tool	Environment	Products and technology
Smith ¹⁷	Long-term rehab. Weathering the winter in a wheelchair	Tool	Environment	Products and technology
Tadano et al ¹⁸	Driving tests and computer simulations of electric wheelchairs on snow-covered roads	Tool	Environment	Products and technology
Bennett and Murphy ¹⁹	Slipping cane and crutch tips. I. Static performance of current devices	Tool	Environment	Products and technology
Kim et al ²⁰	Travel in adverse winter weather conditions by blind pedestrians: effect of cane tip design on travel on snow	Tool	Environment	Products and technology
McKiernan ²¹	A simple gait-stabilizing device reduces outdoor falls and non-serious injurious falls in fall-prone older people during the winter	Tool	Activity	
Yamaguchi et al ²²	Efficacy of a rubber outsole with a hybrid surface pattern for preventing slips on icy surfaces	Tool	Environment	Products and technology
Morales et al ²³	Winter: public enemy #1 for accessibility, exploring new solutions	Recommendations	Environment	Services, systems, and policies
Berthold et al ²⁴	Pressure mapping to assess seated pressure distributions and the potential for skin ulceration in a population of sledge hockey players and control subjects	Recommendations	Body structure/function	
Lindsay et al ²⁵	The experiences of participating in winter among youths with a physical disability compared with their typically developing peers	Recommendations	Participation	

(continued on next page)

Table 1 (continued)

Author	Article Title	Tool, Strategy, Resource, or Recommendation	Primary ICF Domain	Environmental Factor
Odderson et al ²⁶	Gel wheelchair cushions: a potential cold weather hazard	Tool	Environment	Products and technology
Green et al ²⁷	Toward enabling winter occupations: testing a winter coat designed for older adults	Tool	Body structure/function	
Ripat et al ²⁸	Exploring winter community participation among wheelchair users: an online focus group	Recommendations	Participation	
Borisoff et al ²⁹	Seasonal patterns of community participation and mobility of wheelchair users over an entire year	Resource	Participation	
Brandt et al ³⁰	Older people's use of powered wheelchairs for activity and participation	Resource	Participation	
Morales et al ³¹	Addressing challenges for youths with mobility devices in winter conditions	Tool	Environment	Products and technology
Shirado et al ³²	Outdoor winter activities of spinal cord-injured patients. With special reference to outdoor mobility	Recommendations	Environment	Products and technology
Wall ³³	An exploratory study of how travelers with visual impairments modify travel techniques in winter	Strategy	Activity	

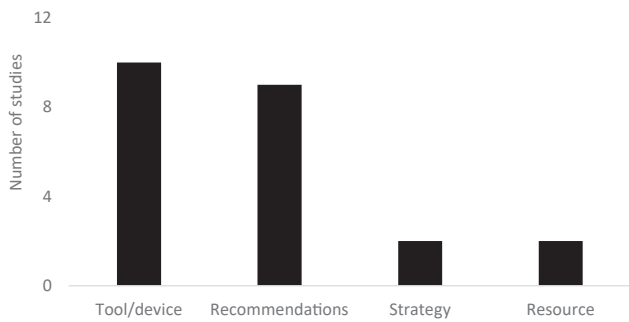


Fig 3 Primary focus of peer-reviewed studies (n=23).

winter-related recommendations related to the services and systems component of environmental factors.^{37,38} Two conference proceedings were located that had not been subsequently published in a peer-review article: both focused on use of products and tools in a simulated winter environment.^{39,40}

The search of Government of Canada documents identified 3 documents that mentioned winter conditions of snow or ice published in the last decade. Of the 3 documents, 1 document was subsequently published in peer-reviewed literature² and the other 2 provided recommendations at the level of environmental factors, systems, and services (eg, keep entrances clear of snow, recommendations regarding responsibilities for snow clearing). Civic documents regarding snow-clearing and transportation policies were identified as resources, addressing the systems, services, and policies level of the environment. Review of the sidewalk snow removal policy documents of 18 major Canadian cities indicated that sidewalk clearing was a mixed responsibility (city and home owner [n=12], the responsibility of the city [n=5], or the responsibility of the property owner [n=1]). With the exception of 2 jurisdictions, a city road clearing priority system was outlined for all other cities. Review of paratransit policy indicated 12 cities stipulate it is the client’s responsibility to clear snow from pick-up and drop-off locations; 2 cities state that the pick-up and drop-off locations should be cleared but do not clearly specify that it is a client responsibility; 1 city states it is a transit responsibility to ensure accessible transit stops; and 3 cities do not address snow clearance at pick-up or drop-off locations. Only 1 city identified transportation policy related

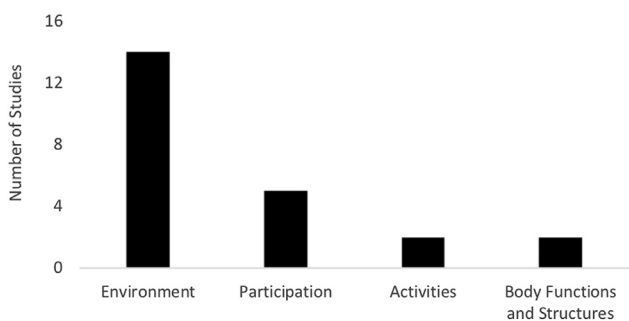


Fig 4 ICF domain addressed in peer-reviewed literature (n=23).

to changing weather conditions, that is, some clients were deemed *snow and ice customers* and eligible for paratransit when snowy or icy conditions were forecast for the date of travel and others were deemed *cold weather customers* and eligible to use the services when temperatures were predicted to be -15°C or colder for the date of travel. Thirteen policy documents indicated the possibility of reduced or canceled service based on inclement weather.

The websites of organizations known to the team to provide supports or services to mobility device users were categorized as resources and identified at the *supports and relations* level of the environment. Of the 28 independent living organization websites searched, 6 provided consumer tips and anecdotal information for safe winter mobility. Similarly, only 8 of 23 Canadian mobility device user organization websites searched, and 5 of 16 United States sites searched, discussed winter-related issues for those with mobility impairments, including consumer tips, 1 review of a research article, and 1 policy recommendation. Three websites were located that provided lists of accessible locations for winter-based activities (eg, skiing, hiking trails).

A dearth of equipment (categorized as tools; environment—*products and technology*) targeted at winter mobility was identified on vendor and manufacturer sites or located through a google search. Overall, 54 products were identified: 15 were sports related (adapted skis); 8 were *all-terrain* power mobility or attendant supported manual wheelchair devices where the manufacturer purported the ability to maneuver through snow; 7 items were winter clothing related; 7 items were cane tip attachments for use on ice; 6 items related to outdoor access to the home in winter (stair lifts, ramps); 4 were antislip devices for shoes; 2 were caster attachments for manual wheelchairs; 2 were wheelchair cushion products intended to provide added warmth when seated; 2 related to scooter accessories for winter conditions; and 1 was a hand warmer for power wheelchair users.

Discussion

The findings confirmed the specific challenges faced in winter that affect community participation. Most of the research in the area of winter mobility and participation targeted environmental factors and was generally focused on either measuring this effect or exploring ways to ameliorate the context. Winter mobility and community participation are not population- or disability-specific issues; the scoping review studies corroborated multiple environmental influences beyond just the mobility device itself. Although products and technologies were the focus of almost half of the located papers, not all studies evaluated product performance and the wide diversity in products tested, methods used, and product user populations makes definitive conclusions on performance effectiveness impossible. Products with at least some minimal performance evaluation included wheelchair casters,¹⁶ power wheelchairs,^{17,18} mobility scooters,^{35,39} cane or crutches,^{19,20,40} and shoes or cleats.^{21,22,34,36} Although there are some winter-specific products available on vendor websites, most of them do not have any supporting research evidence.

There was a lack of high-quality studies investigating categories of products within the wide range and nature of technologies with the potential for improving winter mobility and participation; only 1 randomized control trial was identified.²¹ Furthermore, only 1 study investigated potential design solutions to improve winter mobility.²³ Despite evidence that community participation among individuals with mobility impairment is substantially impeded by winter conditions and that environmental factors (including device, context, service or policy) are implicated, the amount of research specifically addressing these impacting factors is limited. The reasons behind this paucity of literature is unclear. Winter conditions apply to a subset of individuals with mobility impairment, based on geography; recruitment and access to this population may be more challenging and researchers in more temperate climates may lack awareness or interest in these issues. Conducting research in winter conditions is difficult, including uncomfortable conditions for participants and challenges with creating consistency in data collection. Standardization of testing conditions and procedures,³⁵ repetition of product testing, and testing with various populations are all critical components in overcoming this research gap; these should be addressed in imminent research. The sparsity of winter-specific products or technology suggests a lack of product research and development; people using mobility devices in the winter appear to be a large, untapped consumer market.

Overall, only 2 of the peer-reviewed articles located focused on providing strategies on how to move about in

winter.^{7,24} However, many of the consumer websites provided anecdotal and general winter safety tips. This research gap signals a need to identify, confirm, and obtain evidence to support these safe mobility approaches. Winter conditions present particular safety hazards for mobility devices users. Slippery surfaces increase the risk of falls for those who use ambulation aids. Snow and ice can present challenges for wheelchair and mobility scooter users to obtain traction and increase the risk for tips and falls, as well as stranding users.⁴¹ Research documenting prevalence of accidents or injury, safe strategies for winter mobility, and mobility training in winter conditions²⁵ is warranted.

Protection from thermal injury was an area of concern identified on consumer websites and a few targeted products were located on vendor websites (eg, cushion or hand protection when using mobility devices). However, only 2 peer-reviewed studies addressed the potential for thermal injuries (gel-filled wheelchair cushions)²⁶ or warmth (winter coat design).²⁷ Given the health risks of thermal injury, more research on adaptive winter clothing²⁵ and mobility device adaptation is indicated. Rehabilitation and mobility researchers would benefit from seeking out experts in high-performance textiles as partners in future research and development.

The need for improved snow and ice removal policy and procedures has been highlighted in several studies^{3,4,7,25,28,29} because minimal investigation has been conducted in this area.^{23,38} Current Canadian civic policy documents do address aspects of snow clearing, but only

Table 2 Gray literature summary of findings

Source	Findings	Tool, Strategy, Resource, or Recommendation	Primary ICF Domain	Environment
Government of Canada ⁸	2 documents	Recommendations	Environment	Systems, services, and policies
Theses	Denbeigh ³⁴ Ohri ³⁵ Hsu ³⁶ Leckie ³⁷ Joshi ³⁸	Tool Recommendations	Environment	Products and tools, systems, services, and policies
Conference proceedings	Montgomery et al ³⁹ Bouabalos et al ⁴⁰	Recommendations Tool	Environment	Products and tools
Provincial health websites	Unable to search			
City policy—snow clearing	18 policies located and reviewed	Resource	Environment	Systems, services, and policies
City policy—accessible transportation	18 policies located and reviewed	Resource	Environment	Systems, services, and policies
Consumer support—independent living centers	28 consumer websites searched: 6 met inclusion criteria	Resource	Environment	Supports and relations
Canadian mobility device user organization	23 Canadian mobility device user organization websites searched: 8 met inclusion criteria	Resource	Environment	Supports and relations
United States mobility device user organization	16 United States mobility device user organization websites searched: 5 met inclusion criteria	Resource	Environment	Supports and relations
Vendor/manufacture sites	50 devices located	Tool	Environment	Products and tools

one-quarter identified sidewalk clearing as solely a city responsibility; for individuals who use mobility devices, the ability to independently shovel snow and ice may be curtailed, unsafe, or impossible. Existing Canadian civic policy is centered on road clearing and vehicular traffic rather than pedestrian traffic. Some cities in Sweden have recently adopted snow-clearing policies that prioritize clearing of pedestrian and bicycle traffic routes; examining the effects of this policy on people who use mobility devices would be beneficial. Several studies identified the importance of access to safe and accessible transportation as a key component in maintaining community participation throughout the winter.^{7,28,29,37} Examination of the para-transit policy document revealed a somewhat punitive approach to use of services in winter, where individuals using these services were expected to keep pick-up and drop-off locations clear of snow and ice. Given that para-transit service users typically experience mobility restrictions, development of novel solutions that intersect health, social, and transportation services is justified.

Findings from peer-reviewed literature confirmed a real issue of social isolation and need for additional supports in winter.^{3,25,28,30} Although it may be expected that support information would be included on consumer organization websites, for the most part this was not the case. Local and national organizations can play a key role by adopting a targeted focus on providing strategies and supports that move from surviving to thriving in winter.

In summary, we found that there was limited overlap between the research literature and the gray literature found on consumer websites and in policy documents. The peer-reviewed research and academic gray literature focused primarily on environmental factors and equipment, but with very little actual evaluation of performance. The few consumer websites that addressed winter provided primarily anecdotal tips and suggestions that have not been examined in research literature. Although policy documents addressed snow removal and paratransit, these areas have also received little attention in the research literature. Creating an online forum, or toolkit, to house research, consumer-based, and policy information on winter mobility would allow researchers to identify areas of needed research based on consumer-identified and policy issues, consumers and service providers to become aware of emerging evidence and to influence knowledge creation, and developers and innovators to identify consumer-based needs.

Study limitations

Limitations in this study relate mainly to the gray literature search, which was nonexhaustive due to the challenges of searching web-based material, limited to materials written in English or French. Although some organizations and products may have been missed, conducting the search with as much rigor as feasibly possible provides a good indication that there are very few winter-specific devices and limited knowledge. Given the country of residence of the team members, only Canadian government and policy documents were included. Although the team had intended

to search provincial health documents, this was unfeasible due to a lack of sophisticated search engines on individual provincial health websites and this information was not included. Annual conference proceedings from some years were not available online or through e-mail contact with the association. Although relevant to future work, we excluded literature that addressed surface conditions related to falls when the research did not specify a focus on individuals with mobility impairments (eg, Kevern et al⁴²). Stakeholder consultation was identified as an optional step in a scoping review.¹² Although not conducted as part of this scoping review, the larger study (development of a toolkit) will engage various stakeholders (ie, people using mobility devices, service providers, representatives of disability specific organizations) to provide input and feedback on the scoping review findings through a series of online focus groups (people using mobility devices) and online surveys (all stakeholders).

Conclusions

Despite the common experience of challenging winter conditions, there is a paucity of research and innovation in this important area. Not unexpectedly, existing research has been conducted in countries where the population experiences below freezing temperatures during winter months. Although most of the studies have been conducted in Canada, many focused on providing recommendations only and intervention-based and effectiveness research is lacking.

This scoping review served a twofold purpose: to methodically collect and collate available evidence to identify useful information that could be incorporated in a future toolkit, and to identify knowledge gaps with no or low-level research evidence. Additional tools, strategies, resources, and evidence-based recommendations are acutely needed to provide and share information; this is best done through the development of collaborations among the many stakeholders interested in promoting winter mobility and community participation among those who use mobility devices. This scoping review provides the foundation for these future developments.

Corresponding author

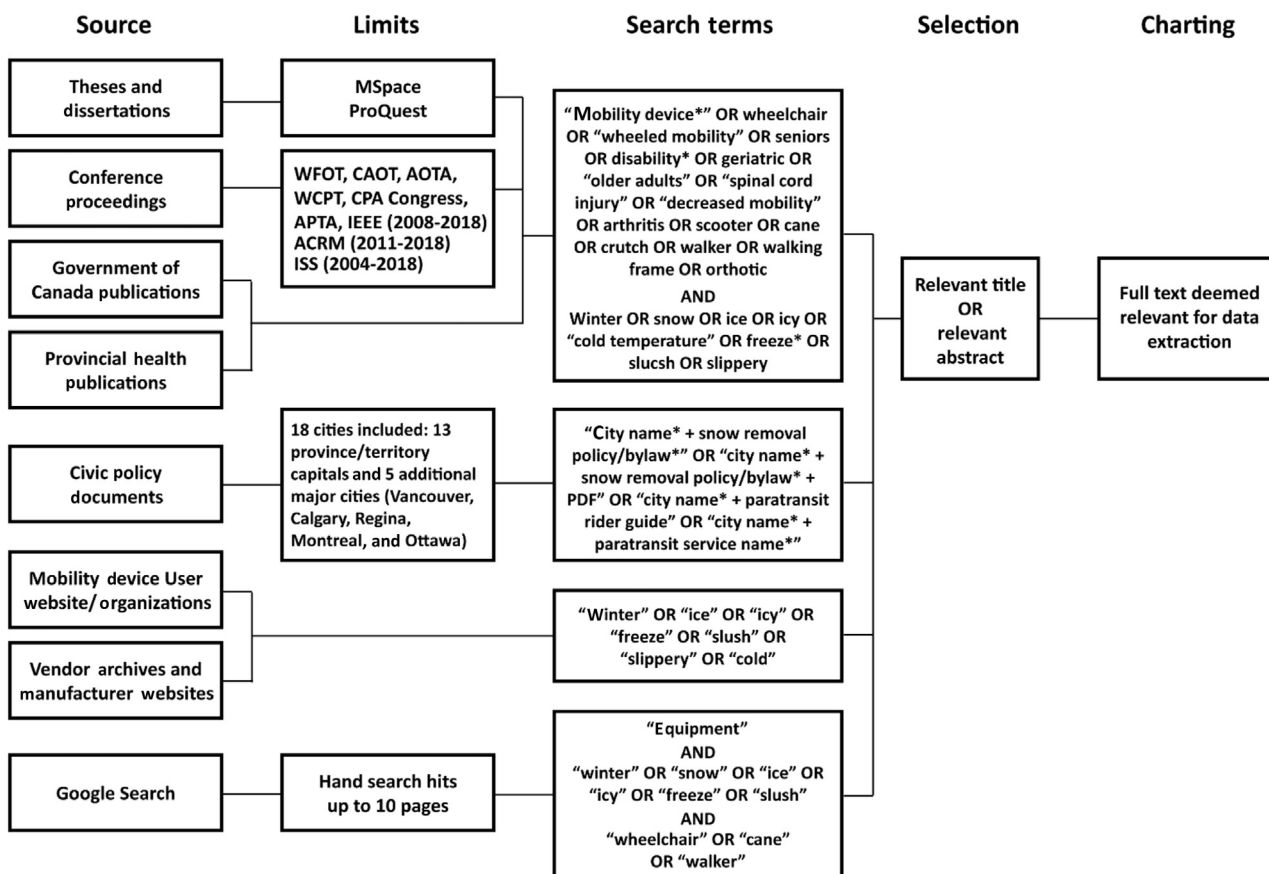
Jacque Ripat, PhD, Department of Occupational Therapy, College of Rehabilitation Sciences, Rady Faculty of Health Sciences, University of Manitoba, R215-771 McDermot Avenue, Winnipeg, Manitoba R3E 0T6, Canada. *E-mail address:* Jacque.Ripat@umanitoba.ca.

Acknowledgments

We thank Hal Loewen for developing the search strategies and Dale Stevenson for his assistance with the gray literature search.

(wheelchair* OR seniors OR disability* OR geriatric) OR (older ADJ adults) OR (spinal ADJ cord ADJ injury) OR (arthritis OR scooter OR cane OR crutch OR walker OR orthotic) OR (walking ADJ frame) OR (fall ADJ prevention) OR (limited OR reduced OR wheeled OR decreased) ADJ3 (mobil*)
AND
(winter OR "cold temperature") OR (ice OR icy OR snow* OR freez* OR slush* OR slippery OR frozen) ADJ3 (surface* OR sidewalk* OR road* OR street* OR walkway* OR path*)

Appendix 1 Sample Search Strategy for OVID



Appendix 2 Gray Literature Search Process

References

- Clarke PJ, Yan T, Keusch F, Gallagher NA. The impact of weather on mobility and participation in older US adults. *Am J Public Health* 2015;105:1489-95.
- Lemaire ED, O'Neill PA, Desrosiers MM, Robertson DG. Wheelchair ramp navigation in snow and ice-grit conditions. *Arch Phys Med Rehabil* 2010;91:1516-23.
- Ripat JD, Brown CL, Ethans KD. Barriers to wheelchair use in the winter. *Arch Phys Med Rehabil* 2015;96:1117-22.
- Li Y, Hsu JA, Fernie G. Aging and the use of pedestrian facilities in winter: the need for improved design and better technology. *J Urban Heal Bull New York Acad Med* 2012;90:602-17.
- Lindsay S, Yantzi N. Weather, disability, vulnerability and resilience: exploring how youth with physical disabilities experience winter. *Disabil Rehabil* 2014;36:2195-204.
- Wee J, Paterson M. Exploring how factors impact the activities and participation of persons with disability: constructing a model through grounded theory. *Qual Rep* 2009;14:165-200.
- Ripat J, Borisoff JF, Grant LE, Chan FHN. Patterns of community participation across the seasons: a year-long case

- study of three Canadian wheelchair users. *Disabil Rehabil* 2018;40:722-31.
8. Government of Canada. Historical climate data. Available at: <http://climate.weather.gc.ca/>. Accessed June 11, 2019.
 9. Rantakokko M, Iwarsson S, Vahaluoto S, Portegijs E, Viljanen A, Rantanen T. Perceived environmental barriers to outdoor mobility and feelings of loneliness among community-dwelling older people. *J Gerontol A Biol Sci Med Sci* 2014;69:1562-8.
 10. Tricco AC, Lillie E, Zarin W, et al. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. *Ann Intern Med* 2018;169:467-73.
 11. Mahood Q, Eerd DV, Irvin E. Searching for grey literature for systematic reviews: challenges and benefits. *Res Synth Methods* 2014;5:1-36.
 12. Arksey H, O'Malley L. Scoping studies: towards a methodological framework. *Int J Soc Res Methodol Theory Pract* 2005;8:19-32.
 13. Levac D, Colquhoun H, O'Brien KK. Scoping studies: advancing the methodology. *Implement Sci* 2010;5:69-77.
 14. World Health Organization. International Classification of Functioning, Disability, and Health. Available at: <https://www.who.int/classifications/icf/en/>. Accessed March 2, 2018.
 15. Schneidert M, Hurst R, Miller J, Bedirhan U. The role of environment in the International Classification of Functioning, Disability and Health (ICF). *Disabil Rehabil* 2003;25:588-95.
 16. Berthelette M, Mann DD, Ripat J, Glazebrook CM. Assessing manual wheelchair caster design for mobility in winter conditions. *Assist Technol* 2018:1-7.
 17. Smith L. Weathering the winter in a wheelchair. *Long-Term Rehab* 2000:62-4.
 18. Tadano S, Tsukada A, Shibano J, Ukai T, Watanuki Y. Driving tests and computer simulations of electric wheelchairs on snow covered roads. *JSME Int J Ser C, Mech Syst Mach Elem Manuf* 1998;41:68-75.
 19. Bennett L, Murphy E. Slipping cane and crutch tips. Part I static performance of current devices. *Bull Prosthet Res* 1977:71-99.
 20. Kim DS, Emerson RW, Gaves E. Travel in adverse winter weather conditions by blind pedestrians: effect of cane tip design on travel on snow. *J Vis Impair Blind* 2016;110:53-8.
 21. Mckiernan FE. A simple gait-stabilizing device reduces outdoor falls and nonserious injurious falls in fall-prone older people during the winter. *J Am Geriatr Soc* 2005;53:943-7.
 22. Yamaguchi T, Hsu J, Li Y, Maki BE. Efficacy of a rubber outsole with a hybrid surface pattern for preventing slips on icy surfaces. *Appl Ergon* 2015;51:9-17.
 23. Morales E, Gamache S, Edwards G. Winter: public enemy #1 for accessibility exploring new solutions. *J Access Des All* 2014;4:30-52.
 24. Berthold J, Dicianno BE, Cooper RA, Berthold J, Dicianno BE, Cooper RA. Pressure mapping to assess seated pressure distributions and the potential risk for skin ulceration in a population of sledge hockey players and control subjects. *Disabil Rehabil Assist Technol* 2013;8:387-91.
 25. Lindsay S, Morales E, Yantzi N, Vincent C, Howell L, Edwards G. The experiences of participating in winter among youths with a physical disability compared with their typically developing peers. *Child Care Health Dev* 2015;41:980-8.
 26. Odderson IR, Jaffe KM, Sleicher CA, Price R, Kropp RJ. Gel wheelchair cushions: a potential cold weather hazard. *Arch Phys Med Rehabil* 1991;72:1017-20.
 27. Green SL, Boger JN, Mihailidis A. Toward enabling winter occupations: testing a winter coat designed for older adults. *Can J Occup Ther* 2011;78:57-64.
 28. Ripat J, Colatruglio A. Exploring winter community participation among wheelchair users: an online focus group. *Occup Ther Heal Care* 2016;30:95-106.
 29. Borisoff JF, Ripat J, Chan F. Seasonal patterns of community participation and mobility of wheelchair users over an entire year. *Arch Phys Med Rehabil* 2018;99:1553-60.
 30. Brandt A, Iwarsson S, Stahle A. Older people's use of powered wheelchairs for activity and participation. *J Rehabil Med* 2004;36:70-7.
 31. Morales E, Lindsay S, Edwards G, et al. Addressing challenges for youths with mobility devices in winter conditions. *Disabil Rehabil* 2018;40:21-7.
 32. Shirado O, Shundo M, Kaneda K, Strax T. Outdoor winter activities of spinal cord-injured patients: with special reference to outdoor mobility. *Am J Phys Med Rehabil* 1995;74:408-14.
 33. Wall RS. An exploratory study of how travelers with visual impairments modify travel techniques in winter. *J Vis Impair Blind* 2001;95:752-6.
 34. Denbeigh K. Slips during gait on winter surfaces: evaluation of ice cleat design and slip definition [master's thesis]. Toronto, Ontario, Canada: University of Toronto; 2013.
 35. Ohri V. Developing test methods for the evaluation of scooter performance in winter conditions [master's thesis]. Toronto, Ontario, Canada: University of Toronto; 2013.
 36. Hsu JA. Measuring the slip resistance of winter footwear [master's thesis]. Toronto, Ontario, Canada: University of Toronto; 2015.
 37. Leckie A. Improving accessibility to transit: an examination of the public transportation system for older adults in Winnipeg, Manitoba [master's thesis]. Winnipeg, Manitoba, Canada: University of Manitoba; 2017.
 38. Joshi D. Understanding experiences of key stakeholder groups regarding sidewalks accessibility in winter for wheeled mobility device users [master's thesis]. Winnipeg, Manitoba, Canada: University of Manitoba; 2014.
 39. Montgomery R, Li Y, Dutta T, Fernie G. Quantifying mobility scooter performance in winter environments. Paper presented at: 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBS). Milan, Italy; 2015.
 40. Boubalos J, Murnaghan LM, Li Y, Kelley S, Narayanan U, Alman BA, Fernie G. Slippery slope: an analysis of crutch ambulation in winter conditions. Paper presented at: 68th COA Annual Meeting. Winnipeg, Canada; 2013.
 41. Daveler B, Salatin B, Grindler G, Candiotti J, Wang H, Cooper RA. Participatory design and validation of mobility enhancement robotic wheelchair. *J Rehabil Res Dev* 2015;52:739-50.
 42. Kevern JT, King GW, Bruetsch AP. Pervious concrete surface characterization to reduce slip-related falls. *J Perform Constr Facil* 2012;26:526-31.