CHAPTER 9

Walking in Winter

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Abstract: Winter in many parts of Canada and the US is an enormous problem for older people. We know that every winter there are many older people who do not get out of their houses for up to three months because they cannot move around safely in the snow, ice, or slushy conditions. This paper describes our efforts at the Toronto Rehabilitation Institute to address the difficulties faced by vulnerable people in winter. The first challenge comes from identifying their perceptions of problems caused by winter. We have subsequently studied the physiologic response to cold and outdoor walking behaviour in wintry conditions in order to understand the problems in greater depth and be able to develop solutions. Emphasis has also been given to investigation of the reported difficulty donning and doffing winter jackets and coats and the effectiveness and safety of winter footwear. Our continuing effort will be focused on the universal design of streetscapes, street furniture, winter clothing, footwear, and improved assistive mobility devices. We are also determining safe exposure levels to cold weather in order to inform the public of the risks associated with mobility in winter and to provide objective criteria for public agency responses to ensure safety and social interventions to reduce isolation in winter.

INTRODUCTION

Winter presents many challenges to vulnerable older people and people with disabilities. Deaths from cardiovascular and respiratory disease increase (Keatinge, 2002; Mercer, 2003; Näyhä, 2005). Injuries from falls increase (Crawford and Parker, 2003; Kojima *et al*., 2008; Stevens *et al*., 2007) and many people become socially isolated because of the discomfort and fear associated with outdoor mobility on slippery, snow, and slush covered surfaces (Daum and Daum, 1983). Those who have fallen are more likely to restrict their activities than others are (Jang *et al*., 2007; Murphy *et al*., 2003; Shumway-Cook *et al*., 2002). A complete description of problems faced by vulnerable people in winter is missing from the literature. Further study is needed to develop universal design guidelines for outdoor environments, clothing, footwear, and mobility aids, and to develop materials to educate the public on how to reduce risk to physical and mental health in the winter. This paper describes the results of studies conducted during the first winter of a multi-year project.

IDENTIFICATION OF THE PROBLEMS WINTER CAUSES OLDER PEOPLE

The first step in our new project began in the winter of 2003-2004 with a 3-phase program of semi-structured interviews, interview-administered surveys, and a focus group where vulnerable older people were asked to identify the problems that they experience in winter (Row *et al*., 2005a). The interviewer-administered surveys (including instruments assessing balance confidence, health status, social network, loneliness, dependence, fall history, fear of falling, and items probing how weather affects health, mobility, clothing, attitudes, excursions, transportation, and social satisfaction) were completed with 30 older adults, (73% female aged 65-96 years) in Toronto. The older adults with reduced functional capacity reported that they had problems even when the weather is not snowy or icy, but simply cold. We were particularly interested to hear that winter clothing, footwear, and assistive mobility devices are barriers to their physical activity and social participation. Winter clothing was difficult to put on and was described as heavy, bulky, and tiring among older adults experiencing functional limitations. The need to put on winter coats and boots discouraged outdoor excursions. Also, 60% reported avoiding outdoor steps and stairs in icy conditions in winter weather and users of wheeled walkers described them as useless in snowy weather. These difficulties with mobility led to increased physical and social isolation for many older adults in winter. However, we must be careful in our response to these circumstances since attempts to encourage

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increased outdoor activity in winter for vulnerable older adults must be made carefully as these individuals experience increased rates of falls, injuries, illnesses, and mortality when exposed to winter cold (Merrild and Bak, 1983; Stevens *et al*., 2007).

PHYSIOLOGIC RESPONSE TO COLD

The relationship between temperature and death rate is U-shaped with increased mortality during hot and cold temperature extremes and fewest deaths occurring at moderate temperatures (Näyhä, 2005). In the UK, there are 40,000 excess deaths above the yearly minimum mortality level in winter versus 1,000 in summer because extreme cold weather conditions in the UK tend to have a longer duration than heat waves (Keatinge, 2002).

The majority of excess winter deaths (up to 70% in some countries) are the result of strokes and myocardial infarction that can be attributed to exposure to the cold during outdoor excursions (Mercer, 2003). In general, there is approximately a 1% increase in mortality due to coronary heart disease for every 1^{o}C drop in temperature and the numbers of deaths due to cardiovascular disease peaks within 1-3 days following the coldest temperature snap (Donaldson *et al*., 2001). About half of the remaining excess winter deaths are attributed to an increased incidence of respiratory infections (Mercer, 2003) which peak between 12-23 days following extreme cold temperatures (Donaldson and Keatinge, 1997), with the mechanism of death also being a thrombolytic event occurring as a downstream repercussion of the respiratory infection (Eurowinter Group, 1997). Even though the associations between cardiovascular diseases and temperature are well documented, the underlying mechanisms behind these associations are not very well understood in general. One mechanism could be that these exposures act on the cardiovascular system by elevating blood pressure. Cold exposure is known to increase blood pressure by activation of the sympathetic nervous system (Young, 1996). Autonomic nervous system response can be studied by assessing heart rate variability (HRV) while being exposed to repeat cold, which may also provide further insight into the assessment of autonomic cardiovascular regulation and the mechanisms that are involved (Mäkinen *et al*., 2008). Autonomic nervous system responsiveness has been measured in studies examining cold acclimation due to repeated exposures to cold air among young participants (22.5±1.6 yr) (Mäkinen *et al*., 2008). However, to our knowledge, no studies have been published examining the effect of everyday cold exposure on elderly subjects dressed in outdoor winter clothing when exposed to winter conditions. The first stage of this project was to verify the findings of Mäkinen *et al*. (2008), as well as to investigate the effect of brief cold exposures on physiological responses across a broader range of ages (19-39 yr). As the results from the first stage of investigation confirmed that studying HRV provides a reliable noninvasive method for the assessment of autonomic cardiovascular regulation and sympatho-vagal interaction, the second stage of this project is underway to examine the role of winter clothing on autonomic cardiovascular responses to cold stress in older people. By undertaking the project in two stages, we eliminated the possibility of testing vulnerable older people if no effect was found among young adults.

In the first stage of this project, heart rate data was collected from 5 male and 4 female (mean age 27.8 yr, range 19-39 yr) healthy volunteers using an ambulatory monitoring vest (*LifeShirt*, Vivometrics Inc, Ventura CA, USA) set to record continuous R-R interval data at 200Hz. Baseline data were collected for 30 minutes at room temperature. Subjects then put on a winter coat and a pair of fleece gloves and slowly walked 5m to a temperature-controlled room (ambient temperature -5^{o}C) where they stood for 30 minutes. (Fig. **1**) shows the increase in heart rate variability and the decrease in mean skin temperature seen corresponding to exposure to the cold for one typical subject. The details about collecting heart rate and skin temperature data as well as calculating HRV and mean skin temperature have been described elsewhere (Juma *et al*., 2008; Li *et al*., 2007a). Results of this preliminary study showed that heart rate variability is sensitive to cold temperatures. The LifeShirt was found to be an efficient and non-invasive tool for measuring heart rate variability and we will be using it with elderly subjects during the next winter to explore the relationship between the physiologic cold response of older subjects and health. Future analyses will also include power spectral analysis of the R-R intervals, which may elucidate differences in the physiologic responses to exposure to cold on the face vs. peripheral cooling of hands and feet (Fleisher *et al*., 1996; Kinoshita *et al*., 2006; Wirch *et al*., 2006). We anticipate that further study may provide evidence of the importance of protecting the head and neck from exposure to the cold particularly for people with cardiovascular pathology (Donaldson *et al*., 2001; Li *et al*., 2009).

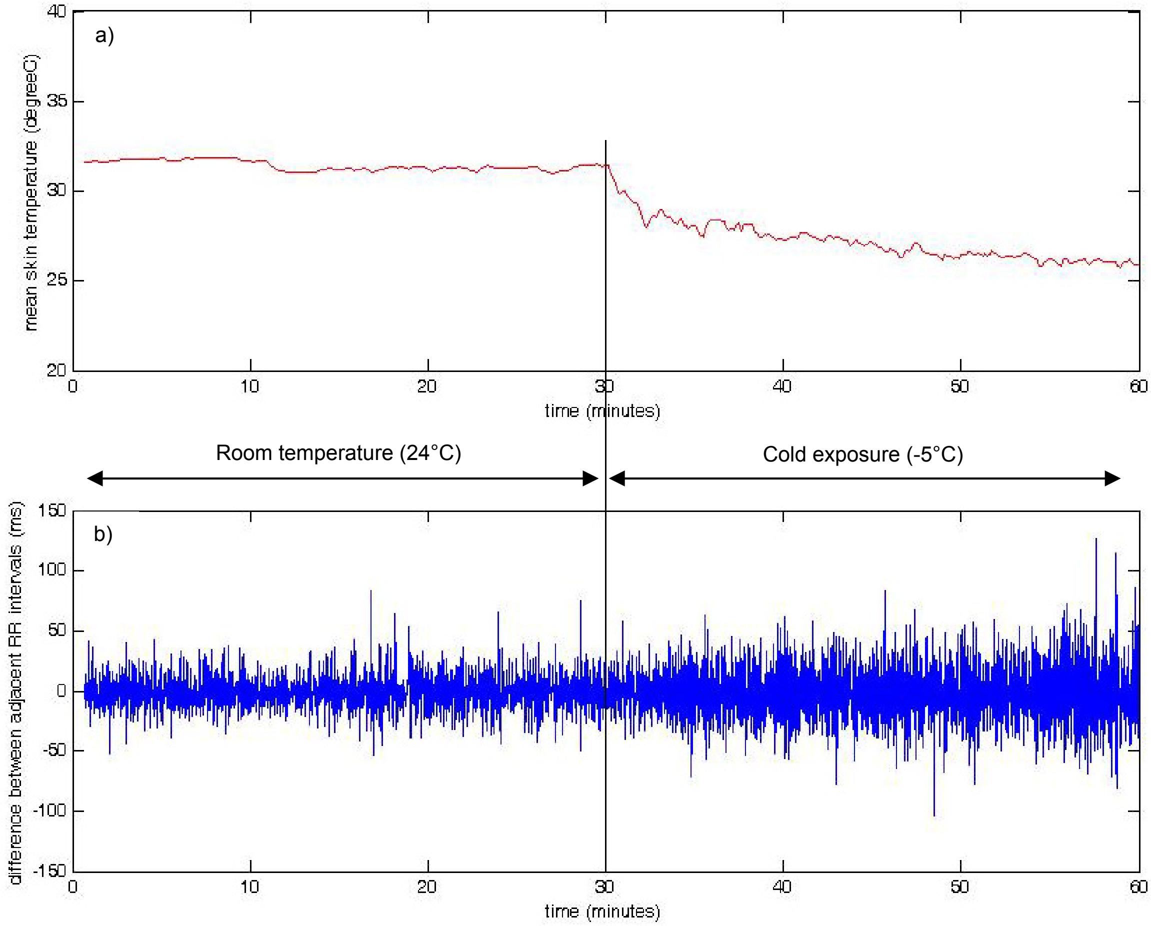

Figure 1: Heart rate variability increases in response to exposure to cold for one typical subject (healthy female, 35 yr). a) Mean skin temperature (°C) based on a weighting formula involving 7 local skin temperatures (Li *et al*., 2007a); b) difference between two adjacent R-R intervals (ms).

PROTECTIVE CLOTHING AND FOOTWEAR

It is interesting and somewhat perplexing that mortality of people aged 50-74 years in Athens increases at temperatures below +23°C, by 2 % per 1°C decline in temperature. In London, mortality increases by 1.4% / °C decline and in Finland the rate of increase is 0.3%/ °C (Eurowinter Group, 1997). In Yakutsk, Siberia, the coldest region of the world, there is no increase in mortality even at temperatures of -48°C (Donaldson *et al*., 1998). Eng and Mercer (2000) have also investigated the geographical differences in outdoor temperatures and mortality rate - revealing differences between Northern Ireland and Norway. The average number of deaths per month increases in Ireland as the temperature drops below about 10°C whereas the same increase is not seen in Norway until it drops below freezing. Of course, these are simply correlations but the suggestion has been made that the level of preparation for winter including the wearing of hats and gloves as well as activity levels outdoors during cold weather may be the cause of these differences (Eurowinter Group, 1997). Therefore, the geographical differences in temperature and mortality rates may have to do with the typical protective clothing worn by individuals in different parts of the world, as the wearing of effective protective clothing reduces the physiologic response to exposure to cold and in turn reduces the likelihood of adverse cardiovascular and respiratory effects (Eurowinter Group, 1997).

We have pursued two areas of focus with respect to winter clothing and footwear. The first is the problem of easy donning and doffing of winter jackets and coats and the second is the effectiveness and safety of winter footwear. One of the first innovations that we are currently continuing to refine in response to testing has been coined "Sleeve Gripper" (patent applied). This invention consists of a cloth handle that can be attached to the inside of the coat in such a way that it can be easily grasped to help insert the second arm into the sleeve and pull the coat on over the shoulder. Inserting the first arm is not difficult particularly if coats are made with wide openings at the shoulder but inserting the second arm requires much greater range of movements and efforts. A preliminary investigation on the use of the Sleeve Gripper by older females who reported functional limitations and difficulty with donning winter coats has demonstrated a reduced muscular exertion required of hand and shoulder muscles during the process of donning and fastening a winter coat (Row *et al*., 2005b). Prototype coats have also been fabricated in our laboratories with features that include novel magnetic fasteners, protective pads to reduce hip fractures, and more effective collar designs to retain heat.

WALKING IN WINTER CONDITIONS

Snow, ice, the cold itself, and reduced daylight make it more difficult for seniors to walk outside in winter and increase their fear of falling (Row *et al*., 2005a). Consequently, there is a need to study outdoor walking in wintry conditions in order to understand the problems and be able to develop solutions. Our initial studies have focused on the speed of walking and on the particularly challenging task of crossing the road in order to provide data that is essential for the development of guidelines for the design of universally accessible street crossings and crossing signals.

Speed of Walking:

Researchers have measured typical walking speeds outdoors (Knoblauch *et al*., 1996; Montufar *et al*., 2007). Our interest is in obtaining a more detailed understanding of the effects of weather and surface conditions on the speed of walking of vulnerable older people and those with mobility limitations. As a first pilot study, we measured the speed of walking along a sidewalk in Toronto between February 2007 and July 2007 using video records of 563 pedestrians. We did not know the ages or identities of these pedestrians who were viewed from a significant distance. The mean walking speed was measured as 1.35 ±0.31m/s (Gupta *et al*., 2008) which is close to that reported by Finnis and Walton (2007) who found a mean walking speed of 1.4 ±0.23 m/s. The lowest walking speeds were seen in our study when the temperature was +15°C and the fastest speeds were seen at –15°C. Colder weather causes pedestrians on average to walk faster probably in an attempt to generate warmth and to spend as little time experiencing discomfort outside as possible. It seems likely that increased speed, in combination with physiologic changes, and the distraction of trying to keep warm might increase the risk of falling even in the absence of slippery ice and snow conditions, as gait variables associated with increased walking velocity reduce the ability to resist a trip or a fall (Pavol *et al*., 1999). Additionally, for vulnerable individuals, protective clothing could restrict movement, dexterity, and field of view further contributing to increased falls.

Crossing the Road:

Busy crossing points have been reported to be sites of increased falls-related injuries during snowy months (Ytterstad, 1999). Visits to emergency centres for falls-related injuries increase dramatically during the period following an ice storm (Lewis and Lasater, 1994; Smith and Nelson, 1998). Previous studies showed that the signal timing for most pedestrian crossings does not allow adequate time for many older pedestrians to cross and puts them at potential risk even in comfortable weather (Hoxie and Rubenstein, 1994; Langlois *et al*., 1997). Crossing the road in winter is a particularly hazardous and difficult task for vulnerable older people and people with disabilities because of the need to move with sufficient speed to complete the crossing within the time allowed by the traffic lights despite hazards which include slippery curb ramps, accumulated water and snow, and furrows made by vehicle wheels and snow clearing equipment.

Older pedestrians are also very vulnerable to injury and death in traffic accidents. They form a disproportionately large proportion of pedestrian fatalities and the majority of these injuries occur at intersections (Transport Canada, 2004). Therefore, we are very interested in including studies of pedestrian behaviour and crossing speeds in a full range of weather conditions as a component of our ongoing winter research program.

During our first winter of study from February 2007 to March 2008, we monitored a road crossing close to our hospital using a high quality video camera recording directly to computer and mounted outside the 12^th^

storey of our building. The crossing is shown in (Fig. **2**). It is across University Avenue, which is a busy wide street with four lanes of traffic in each direction separated by a wide refuge traffic island on the median. Signage emphasizes to pedestrians that this is a two-stage crossing and that they are expected to rest on the median refuge island between the first and second stages of crossing the road. The pedestrian signals display a white icon of a walking figure for 9 seconds followed by a flashing red "Do not walk" figure with a countdown display for a period of a total of 11 seconds. This provides sufficient time to enable most pedestrians to cross the road safely if they stage their crossing by using the refuge island. However, we observed 74% of pedestrians chose to cross the entire street in one stage and among these 86% were not able to reach the other side within the provided signal time (Li *et al*., 2007b; Li and Fernie, 2008). Consequently, those pedestrians were facing a red light when they were approaching the other side of the street. This could increase the risk of pedestrian-automobile collision. Our finding is in line with the results of Hamed (2001), who studied pedestrian crossing behavior on undivided and divided streets. Their findings suggested that pedestrians behaved differently or had different waiting times as they crossed from one side of the street to the refuge and from the refuge to the other side of the street. This has an important message for road designers that refuge islands actually can present additional safety risks at least if the timing does not allow sufficient time for the large proportion of pedestrians who are determined to cross both phases in one traffic light cycle. Perhaps a shelter on the refuge island might encourage more pedestrians to wait for the next green light particularly during cold weather.

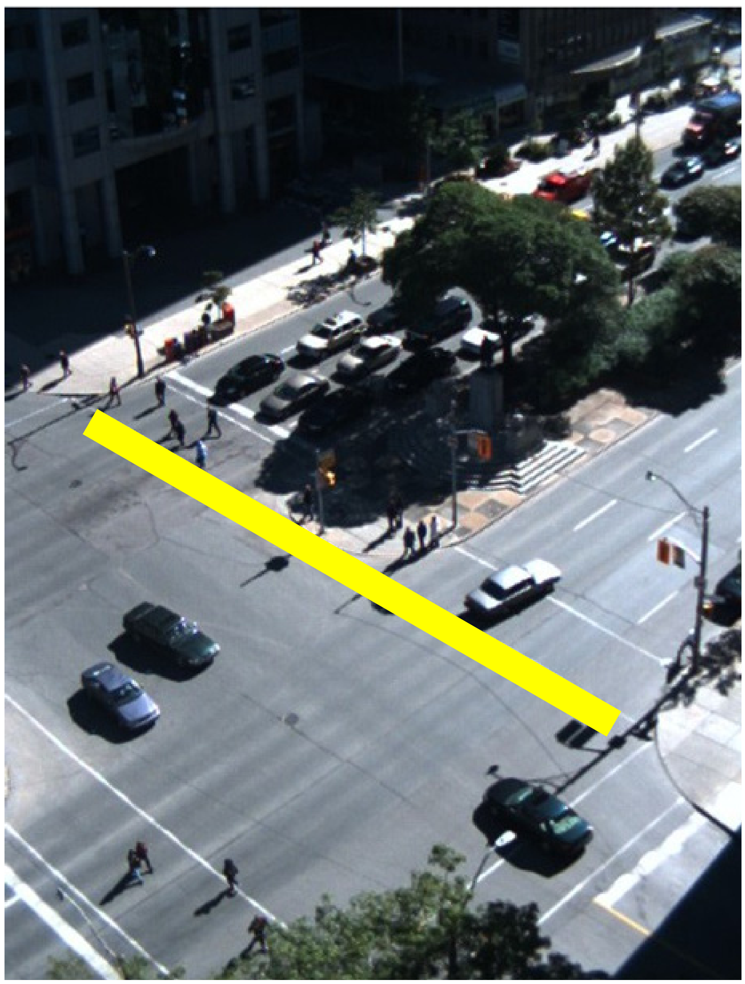

Figure 2: Street crossing (marked in yellow) as seen by the research video camera

Design of Street Crossings:

We have begun to examine the design of streets and the techniques for maintenance of the streets including clearance of snow and ice. Our aim is to contribute to guidelines for improving the universal design of streets so that users of all ages and abilities will experience easier, more comfortable and safer mobility in all weathers. When walking in a city it is necessary to cross roads frequently and this presents the greatest environmental design challenge in the winter. The common solution to overcoming the transition from the raised footpath to the lower road bed at the curb is the curb cut. This is a short ramp that has become popular as an accessibility feature and most crossings at intersections in Toronto are equipped with this feature. However, our observation showed that this solution appears not to function well in winter conditions. Frequently these ramps trap water and become large puddles, see for example (Fig. **3**). Pedestrians have also reported that the curb ramps become slippery in icy conditions and snow and ice accumulate and do not seem to be easily cleared by street maintenance equipment. We are studying the performance of curb cuts in the next few winters with a view to proposing an alternative design for road crossings. Plans include extending this analysis to other important features of streetscapes including bus and transitway stops.

Figure 3: Curb cuts encourage winter accumulations of snow, ice and water. The photo depicts the accumulation of slush and water in the curb cut at the bottom of the photo.

FUTURE RESEARCH

Our goal is to develop guidelines and products that make it easier and safer for everyone to move around outdoors in winter. Attention will be focused on the universal design of streetscapes and street furniture, design of winter clothing and footwear, design of improved assistive mobility devices, determination of safe exposure levels to inform the public of the risks associated with mobility in winter, and consideration of transportation, services, and social interventions to reduce isolation in winter.

Biomechanical and physiologic studies have generally been conducted in indoor laboratories at room temperature. We will continue the development of wearable and portable instrumentation to enable data to be collected in real world environments in winter conditions. We are also currently in the midst of designing and constructing a sophisticated simulator environment which when it opens in early 2011 will provide researchers with extraordinary tools that will include the ability to reproduce winter conditions of ice, snow, and cold winds in a laboratory mounted on a large motion platform that is equipped with an advanced robotic system to protect the subjects from harm, see (Fig. **4**). The motion platform will be able to create slopes of various gradients as well as to move to disturb balance and provoke balance-compensating maneuvers. We invite researchers to consider the potential of using these facilities as a resource to conduct their experiments alongside ours.

Figure 4: A model of the iDAPT Challenging Environments Assessment Laboratory (CEAL) showing the winter simulation environment (inset) mounted on the motion simulator platform. Other laboratory payloads can be seen in the background together with the overhead crane.

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