Mechanical and Physical Risk Prevention

Studies and Research Projects

REPORT **R-893**

Risk Factors for Slip Accidents among Police Officers and School Crossing Guards

Exploratory Study

Chantal Gauvin
David Pearsall
Mohsen Damavandi
Yannick Michaud-Paquette
Bruno Farbos
Daniel Imbeau

The Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), established in Québec since 1980, is a scientific research organization well-known for the quality of its work and the expertise of its personnel.

OUR RESEARCH

is *working* for you !

Mission

To contribute, through research, to the prevention of industrial accidents and occupational diseases and to the rehabilitation of affected workers;

To disseminate knowledge and serve as a scientific reference centre and expert;

To provide the laboratory services and expertise required to support the public occupational health and safety network.

Funded by the Commission de la santé et de la sécurité du travail, the IRSST has a board of directors made up of an equal number of employer and worker representatives.

To find out more

Visit our Web site for complete up-to-date information about the IRSST. All our publications can be downloaded at no charge.
www.irsst.qc.ca

To obtain the latest information on the research carried out or funded by the IRSST, subscribe to *Prévention au travail,* the free magazine published jointly by the IRSST and the CSST.
Subscription: *www.csst.qc.ca/AbonnementPAT*

Legal Deposit
Bibliothèque et Archives nationales du Québec
2015
ISBN: 978-2-89631-834-6 (PDF)
ISSN: 0820-8395

IRSST – Communications and Knowledge
Transfer Division
505 De Maisonneuve Blvd. West
Montréal, Québec
H3A 3C2
Phone: 514 288-1551
publications@irsst.qc.ca
www.irsst.qc.ca

Mechanical and Physical Risk Prevention

Studies and Research Projects

REPORT **R-893**

Risk Factors for Slip Accidents among Police Officers and School Crossing Guards

Exploratory Study

Chantal Gauvin
Prévention des risques mécaniques et physiques – IRSST

David Pearsall, Mohsen Damavandi, Yannick Michaud-Paquette
Université McGill

Bruno Farbos, Daniel Imbeau
École polytechnique de Montréal

This study was funded by the IRSST. The conclusions and recommendations are solely those of the authors.
This publication is a translation of the French original; only the original version (R-856) is authoritative.

PEER REVIEW

In compliance with IRSST policy, the research results published in this document have been peer-reviewed.

ACKNOWLEDGEMENTS

The authors would like to take this opportunity to thank all members of the follow-up committee for their invaluable collaboration in the realization of this study. We also wish to express our gratitude to all the individuals who volunteered to participate in the focus groups. Our thanks go as well to our colleagues at the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), particularly to François Ouellet, for his sound advice and his contribution to the results synthesis, and to Chantal Tellier, Pascale Prud'homme, and Alexandre Boucher for their help in the statistical analysis of the accidents studied.

SUMMARY

Between 2005 and 2007, occupational accidents involving slips, trips, and falls (STFs) on the same level represented 12.6% of all injuries compensated by the Commission de la santé et de la sécurité du travail du Québec (CSST) and resulted in payouts of $90 million. Two occupational groups—police officers and school crossing guards—approached the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST) for its assistance in reducing and/or preventing slip incidents, which overall represent nearly half of all STF accidents. An exploratory study was carried out to document the problem and ultimately to better target preventive measures. The main objective was to identify the risk factors associated with slipping incidents/accidents in order to propose possible future research avenues that will help meet these workers' needs. The research activity was carried out in collaboration with organizations working to prevent accidents and preserve occupational safety.

This activity was carried out in three steps: (1) a review of the scientific literature, which led to the production of a knowledge inventory on the slip problem for the purpose of identifying the risk factors in general terms, understanding the mechanics of human movements on slippery and inclined surfaces, and establishing the relationships between footwear and accidents; (2) an examination of descriptive statistics on slip accidents/incidents among police officers and school crossing guards for the 2007–2009 period, in order to determine the circumstances under which these events occur and to assess the relative importance of the various risk factors in the two target populations; and (3) focus groups held with police officers, school crossing guards, and highway controllers, in order to gain insight into possible relationships between the various risk factors and to tackle the issue of worker footwear.

The results obtained in this study led to a proposed model that provides an overview of the risk factors for the target populations, the interaction among these factors, and their level of impact on the risk of slip accidents. This comprehensive approach to the problem allows for better targeting of preventive measures. The model shows slip accidents as the result of interactions among various risk factors. Friction at the footwear/underfoot surface interface is immediately associated with these accidents as it constitutes the primary risk factor. It is followed by secondary risk factors, which have a direct impact on these slips and characterize the friction at the footwear/ground interface. These secondary factors may be intrinsic, in this case physiological or behavioural, or extrinsic, that is, related to the physical work environment or the work activity. Lastly, the third category of risk factors includes aspects of how work is organized that have a broader impact on the presence of secondary risk factors or their level of impact.

Recommendations for work organizations and for future research were put forward following this activity. Proposals were also made about possible research avenues to be pursued in order to meet prevention needs more effectively and address problems for which no solutions are offered in the scientific literature. These concern mainly outdoor surfaces, particularly under winter conditions, and stairs. The proposed research avenues include more in-depth study of the role of the risk factors, study of the mechanisms of human movement on slippery surfaces with a view to developing postural control and accident prevention strategies, and furthering knowledge on the relationship between footwear characteristics and slip accidents in snowy, icy conditions.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1 Occupational health and safety problem

Many studies have shown that slips and falls are among the leading causes of occupational accidents. In Québec, falls on the same level and slips/trips without falls top the list of most frequent types of occupational accidents[1]. Between 2005 and 2007, slips and falls accounted for 12.6% of all injuries compensated by the Commission de la santé et de la sécurité du travail du Québec (CSST) and resulted in payouts of $90 million during that period. From 2000 to 2008, while the average annual number of injuries associated with slips and falls decreased by around 12.2%, their relative proportion increased, up from 10.2% in 2000 to 13.1% in 2008[1]. Yoon and Lockhart (2006) found that between 1999 and 2001, over 20% of injuries occurring in the private sector in the United States were associated with slips and falls. It has also been observed that the slipperiness of underfoot surfaces is a contributing factor in 40 to 50% of fall accidents (Courtney et al., 2001). Preventing slip accidents is clearly a major public health and occupational health and safety issue. We must therefore broaden our understanding of the causes of these accidents in order to develop appropriate intervention strategies.

A number of occupational sectors are affected by this problem. In the municipal affairs and provincial administration sectors, slips and falls represent 22.5% of all 6,000 accidents that occur annually (APSAM, 2007). In addition, the level of injury severity in these sectors is high, since an average of over 40 work days are lost per accident. **Police departments** in both the municipal and provincial sectors are also affected. According to CSST data, this problem accounted for 16.6% of all injuries that occurred in police departments between 2005 and 2010 and for 20.2% of the payouts[2]. These accidents include falls on the same level (57% of the cases), slips/trips without falls (26%), and falls involving a small drop height such as in a stairway or when getting out of a stationary vehicle (16%). According to one study conducted by the Service de police de la Ville de Montréal (SPVM) on slip and fall accidents among its police officers for the 2002–2004 period[3], 50% of the accidents involved stairways and foot chases. According to the CSST[2] data, slip and fall incidents/accidents cause mainly sprains/strains (53% of the cases), bruises/contusions (20%), and fractures (10%). The injury sites vary and include the knee, ankle, back, shoulder, hand, and multiple sites. The causal agent of the injury is usually the ground surface (39% of the accidents, mainly falls on the same level), body movement or posture (30% of the cases, mainly slips/trips without falls), and stairways (11% of the cases, mainly falls involving a small drop height). The various factors that contributed to the accidents include ice (21%), followed by cases in which the contributing factors were not specified (18%), and lastly, the worker's body movement or posture (13%).

---

[1] Duguay, P., A. Boucher, M.-A. Busque and P. Prud'homme, 2012, "Indicateurs quinquennaux, Québec, 2005-2007 – Chute au même niveau et glisser/trébucher sans tomber," internal program document, IRSST.

[2] CSST – Commission de la santé et de la sécurité du travail, 2013, Dépôt de données central et régional (DDCR), Data from 2005 to 2010, updated on July 1 of the year x+3, Data processed by the IRSST, October 4, 2013, Montréal, QC.

[3] SPVM – Service de police de la Ville de Montréal, 2010. Joint-committee section (occupational health and safety). Personal communication.

School crossing guards also constitute an at-risk group. A survey of this population revealed that 37% of the respondents had fallen at least once on the job[4]. The survey further revealed that 70% of them had previously slipped without falling and that 59% had previously tripped without falling. To help prevent slip accidents, school crossing guards in the City of Montréal have been wearing cleated soles since 2005 (APSAM, 2006).

For several years now, the joint sector-based associations for occupational health and safety in the municipal affairs sector (APSAM) and the provincial administration sector (APSSAP) have been making considerable efforts to raise awareness of the problem among their clienteles. The two associations have developed four fact sheets designed to help prevent accidents and offer possible solutions to the problem (APSAM, 2007). Municipal and provincial police departments and school crossing guards (who fall under cities or police departments) approached the IRSST for assistance in reducing and/or preventing slip and fall accidents. Since many of these accidents occur on slippery or wet surfaces (snow, ice, rain), the IRSST was asked to assess the possible impacts of footwear sole grip on slip accidents among police officers and school crossing guards.

The problem is complex and various factors contribute to the risk of slipping. As a whole, the studies we reviewed focused systematically on the multifactorial nature of slip accidents since they occur in a wide variety of circumstances. Footwear soling is one aspect that warrants consideration, but not the only one. Other factors tend to predispose workers to accidents in slippery conditions (Grönqvist et al., 2001b). Slips and falls continue to be one of the main causes of accidents[5]. Multidimensional intervention strategies are therefore needed to try to reduce these accidents. In order to do a better job of identifying the preventive interventions needed, it seemed important to document the problem first and then identify some of the risk factors associated with slip accidents. We did so for two specific occupational sectors: police officers and school crossing guards.

1.2 Objectives

The aim of this exploratory research activity was to document the problem of slip accidents by identifying the risk factors associated with both accidents (involving loss of work time) and incidents (involving no loss of work time) in order to propose research avenues that would allow for more effective targeting of preventive interventions. The occupational sectors that had sought the IRSST's assistance in their prevention efforts were the focus of this study: police officers (in the municipal and provincial sectors) and school crossing guards. To achieve this aim, the following specific objectives were defined:

1) Carry out a review of the scientific literature on slip accidents and preventive intervention strategies;

---

[4] SPVM – Service de police de la Ville de Montréal, 2010. Joint-committee section (occupational health and safety). Personal communication.

[5] Duguay, P., A. Boucher, M.-A. Busque and P. Prud'homme, 2012, "Indicateurs quinquennaux, Québec, 2005-2007 – Chute au même niveau et glisser/trébucher sans tomber," internal program document, IRSST.

2) Perform a statistical analysis of the accident and incident data from the target work organizations, using their databases;

3) Hold focus groups with various workers from the target work organizations;

4) Identify the footwear worn by the workers in the target work organizations and explore the relationships between the footwear and slip accidents;

5) Propose possible research avenues that would address the concerns of the target work organizations.

The activity was supported and feedback was provided by a committee comprised of representatives of joint sector-based associations and partners from the municipalities and police departments.

2. CONCEPTS AND METHODS

2.1 Definitions and concepts

This study focused on occupational accidents caused by a **slip** that may or may not have been followed by a fall (i.e. the victims may or may not have recovered their balance).

The term "slips and falls" used in Québec actually designates a broader problem that normally includes all accidents analogous to a slip, trip, misstep, stepping into a hole, or any other loss of balance, regardless of whether or not the person falls. Generally, the types of surfaces on which these accidents can occur are level or sloping (access ramp, inclined surface) or have a small drop height (sidewalk, steps). The abbreviation **STF** (which stands for slips, trips and falls) will be used in this report to designate this problem as a whole. In France, the term "*accidents de plain-pied*" [accidents on the same level] is used to refer to the problem. However, in recent years, efforts have been made to better define this type of accident by introducing the notion of "accidents with movement disturbance" (Leclercq et al., 2010). In the United States, the term "slip, trip and fall (STF) accidents" is used to refer to the problem. The triggering factor (and common point) across this entire event-type spectrum is a perturbation of balance, which may or may not be recovered (Leclercq and Tissot, 2004). Slip accidents thus form a subset of STF-type events in which a loss of balance is caused by footwear slipping on the ground (Leclercq, 1997b).

Slip accidents are multifactorial in nature, meaning that they occur in a wide variety of circumstances. The risk factors may be **extrinsic** (environmental and organizational), **intrinsic** (physiological or behavioural), or **mixed** (systemic) (Grönqvist et al., 2001a and 2001b). The **main risk factor** for slipping is poor grip or low friction between the footwear and the underfoot surface, potentially resulting in a loss of foot traction on the ground (Grönqvist et al., 2001a). Icy and snowy surfaces are common problems for the public at large and particularly for people who work outside (forestry workers, construction workers, service sector workers, etc. [Leamon and Murphy, 1995]). The **secondary risk factors** for slips encompass a broad range of human and environmental factors such as uneven surfaces (e.g. variable textures and degrees of flexibility, variable slopes, stair ascents and descents [Leclercq, 1997a; Chang et al., 2004]), behavioural factors (e.g. movement speed and step length [Cooper and Prebeau-Menezes, 2008]), task-related factors (e.g. visual distractions or load carrying [Bloswick and Love, 1991]), and intrinsic personal factors (e.g. visual, vestibular, proprioceptive, and musculoskeletal functions; balance; illness [Gauchard et al., 2001; Gao and Abeysekera, 2004a]).

A risk factor is generally defined as an aspect of the work environment (physical or organizational) known to be related to an event that is potentially harmful to a worker's health and safety and regarded as important to control, or even eliminate, in order to prevent the harmful event. The primary risk factor is the one that is necessarily present to initiate the slip. Secondary risk factors predispose workers to accidents in potentially slippery conditions (Grönqvist et al., 2001b). These factors may be related to an aspect of the physical or organizational work environment or to an aspect of the worker's behaviour or inherent characteristics (e.g. age, gender, or pathology). The complexity of the factors involved in slip accidents suggests that there is interaction among the environmental, organizational, physiological, and behavioural factors, thus pointing to the need for a broad conceptual framework for analyzing injury etiology and developing appropriate interventions.

2.2 Methods

To identify some of the risk factors associated with slip accidents in police officers and school crossing guards and propose prevention-centred research avenues, this study drew on three sources of information. The first was a **review** of the scientific **literature**, which helped establish the basic concepts underlying our analysis of the other sources of information. The literature review also served to identify the risk factors in overall and general terms (objective 1). The second source of information was the **statistical analysis of accident/incident data** (with and without loss of work time respectively) that occurred in specific work organizations over a period of three consecutive years. This accident/incident analysis allowed us to qualify the magnitude of certain risk factors, especially extrinsic environmental factors and the activity under way at the time of the event, for two specific populations: the police officers in three Québec police departments and the school crossing guards in two Québec cities (objective 2). The third source of information was the **focus groups** held with workers from the target work organizations. These groups provided a better understanding of the relationships among the various risk factors and greater insight into the reasons for the presence of these risk factors (objective 3). The focus groups also shed light on the type of footwear worn by the workers. The relationship between footwear and accident risks, as well as that between footwear soles and slip accidents as established in the literature review, was explored (objective 4). The overall results obtained provided a clearer picture of the target populations' needs and made it possible to propose various research avenues (objective 5).

2.2.1 Search for pertinent literature

The literature review provided an opportunity for examining the conclusions reached in earlier studies regarding the following three themes:

1) The factors involved in slip accidents and their prevention: the primary and secondary risk factors most frequently encountered and studied in the literature were identified. The role of these various risk factors in slip accidents and the intervention strategies for preventing them were reported.

2) The mechanics of human movement on slippery and inclined surfaces: the biomechanical factors that better explain why slippery surfaces cause slip accidents, as well as how balance is controlled during walking and recovered following a slip, were examined.

3) The relationship between footwear and slip accidents: the friction mechanisms at the footwear/underfoot surface interface, the relationship between a slip and sole characteristics, as well as the different approaches to evaluating friction, were explored.

The ScienceDirect, SciVerseScopus, and EBSCO databases were searched using the key words "slip," "falls," and "footwear" to extract pertinent articles. A total of over 400 articles were identified. The search was then narrowed to articles published after 1980 and containing the key words "winter" or "ice." Finally, 80 articles were retained and read.

2.2.2 Descriptive statistics of accidents/incidents among the police officers and school crossing guards

The accident/incident files were analyzed to identify the causes and risk factors for slip accidents in the study populations, specifically, police officers in three police departments and school crossing guards in two cities, over a three-year period. The data came directly from the databases of the work organizations concerned. The analysis cannot therefore be generalized to all police officers and school crossing guards. The collected data were sorted on the basis of the event descriptions to identify those events involving slips. These events were then analyzed in greater depth to determine the relative importance of the various factors.

2.2.2.1 Data collection

Assisted by members of the follow-up committee, the target work organizations provided event files related to STFs. The events comprised occupational accidents involving loss of work time that were reported to the CSST, incidents with no work time lost but for which the files were still sent to the CSST (for claims for broken glasses, for example), a few events involving injury relapses/recurrences or aggravations (with or without loss of work time), as well as incidents with no time loss and no claim. These accident/incident files came directly from the databases maintained by the organizations. A total of three police departments (PD 1 to PD 3) and two cities (City 1 and City 2) provided data on their police officers and school crossing guards respectively. Data was supplied for the three consecutive years 2007, 2008, and 2009, with one exception. For the school crossing guards at City 2, the data pertained instead to events that occurred during 2008, 2009, and 2010 because the 2007 data were no longer readily accessible. The raw data provided by the organizations consisted either of Excel or PDF files generated directly from their databases or of occupational-accident declaration and analysis forms scanned in PDF format. All the data were then compiled in an Excel file for purposes of analysis.

A total of 609 events involving the STF problem were examined. These cases were included in the study after a preliminary sorting of all documents received. Appendix A describes the sort procedure and, for information purposes only, gives the equivalent CSST accident codes (see Table 20, Appendix A). The data on these STF events included at least the following information: gender, age, date of the event, duration of the disability (or date of return to work), and a detailed description of the accident (by the employee and/or employer). Table 1 shows the number of STF files collected for the police officers and the school crossing guards.

Table 1 Distribution of number of STF events for which data provided by three police departments and two cities (2007–2009 for City 1 and 2008–2010 for City 2)

Group	Organization	No. of incidents (with no time loss)	No. of accidents (with time loss)	No. of cases, time loss unknown	Total
Police officers	PD 1	114	120		234
	PD 2	70	2	12	84
	PD 3	133	96		229
	Total	**317**	**218**	**12**	**547**
School crossing guards	City 1	9	25		34
	City 2	13	15		28
	Total	**22**	**40**		**62**
Total		**339**	**258**	**12**	**609**

2.2.2.2 Sorting the events and extracting those related to slip accidents

The 609 STF events retained include, in particular, falls, slips, trips, and other loss-of-balance events. They also include events that occurred in a stairway, jumping over or crossing an obstacle (such as a fence or ditch), and getting into or out of a stationary vehicle, as these are especially pertinent to police work. Based on the CSST coding (see Table 22, Appendix A) among other things, *general* types of accidents/incidents were identified and used to categorize all the events for which data were provided (Table 2).

Table 2 Types of accidents/incidents identified in events for which data provided

General **type of accident/incident**	***Specific*** **type of accident/incident**	
• **Slip, trip, loss of balance with/without fall**	• Slipping on a surface	• Being struck or pushed by ...
Slip, trip, loss of balance with fall	• Falling n.o.s.*	• Being hit by a vehicle
Slip, trip, loss of balance without fall	• Tripping	• Missing a step
• **Fall in a STAIRWAY or on stairs**	• Losing balance	• Stepping on something that gives way
• **Fall when JUMPING OVER or CROSSING …**	• Taking an awkward step	• Stepping on a nail
Fall when JUMPING over …	• Losing footing	• Stepping into a hole
Fall when CROSSING …	• Twisting a foot	• Falling into a hole
• **Fall when getting into/out of a stationary VEHICLE**	• Banging into ...	• Stepping into midair
	• Being dragged along by …	

* n.o.s.: not otherwise specified

In order to extract the slip-related events, *specific* types of accidents/incidents were also identified using an inductive method, i.e. by reading all the accident descriptions and pooling the terms used. For example, the descriptive phrases “I slipped,” “I lost my footing,” I lost my balance” and “I took an awkward step” were treated as *specific* types of accidents/incidents. Table 2 summarizes the *general* and *specific* types of accidents/incidents identified. All events for which the descriptions mentioned that the worker had slipped were classified under the “Slipping on a surface” item. Events whose descriptions did not use the phrase “I slipped” but specifically mentioned a slippery surface (e.g. “I lost my footing on the ice” or “I lost my balance because the floor was slippery”) were also classified under the “Slipping on a surface” item.

Table 3 Types of slip-related accidents/incidents

General **type of accident/incident**	***Specific*** **type of accident/incident**
• **General slip with/without fall**	• Slipping on a surface
General slip with fall	
General slip without fall	
• **Slip in a STAIRWAY or on steps**	
• **Slip when JUMPING over or CROSSING …**	
Slip when JUMPING over …	
Slip when CROSSING …	
• **Slip when getting into/out of a stationary VEHICLE**	

A total of 329 slip events were extracted from all the STF files obtained. Slips occurred in each of the general types of accidents/incidents. For the sake of consistency in the presentation of the results specific to slips, all the general types of accidents/incidents were renamed using the term "slip," as shown in Table 3. Table 4 shows the distribution of slips with and without time loss, for the police officers and school crossing guards.

Table 4 Distribution of number of slip events for which data provided by three police departments and two cities (2007–2009 for City 1 and 2008–2010 for City 2)

Group	Organization	No. of incidents (with no time loss)	No. of accidents (with time loss)	No. of cases, time loss unknown	Total
Police officers	PD 1	55	60		115
	PD 2	52	2	9	63
	PD 3	83	40		123
	Total	**190**	**102**	**9**	**301**
School crossing guards	City 1	3	10		13
	City 2	10	5		15
	Total	**13**	**15**		**28**
Total		**203**	**117**	**9**	**329**

2.2.2.3 Data analysis

The same data analysis method was used for both the police officers and the school crossing guards, but the results were compiled separately for the two groups. The results presented in this report are limited to the events that occurred in the three police departments and two cities under study. Slips represented a major proportion of all the STFs, in fact, roughly half of the events retained. However, as the other events also represented a part of the STF problem, all the data for them were also analyzed and are presented in Appendix B.

2.2.2.3.1 Identification of risk factors

Various risk factors associated with the accidents/incidents were identified using an inductive method and based exclusively on the event descriptions. These descriptions were written by the worker, the employer, or a co-worker (i.e. in the first or third person singular). The level of detail provided on the circumstances surrounding the events allowed some secondary extrinsic risk factors to be identified for most of the events. The risk factors examined in the statistical analysis are listed in Table 5 for the police officers and Table 6 for the school crossing guards. The first-level **environmental** risk factors included the nature of the ground or underfoot surface (icy/snowy ground, access ramp, etc.), the use of cumbersome or inappropriate equipment (e.g. object/equipment, inadequate footwear), and space constraints (e.g. poor visibility, the presence of a vehicle). Details on the general location of the event (inside or outside, at the police station, etc.) and on the lack of visual cues (darkness, ice hidden under the snow, etc.) were also compiled. These second-level specifications served to detail the first-level environmental risk factors when pertinent to the results analysis. For the organizational risk factors, the type of **activity/task** underway at the time of the event may have been examined. The activity may have included work periods involving different exposure to the risk, for example, when the activity led the worker to make rapid movements, change position suddenly, or assume a state of alert. Activities related directly to the job, i.e. requiring an intervention with the public and a degree of concentration, were distinguished from "other" activities, i.e. not directly job-related, such as breaks or arriving at or leaving work. These two categories were then broken down into various activities/tasks. Risk factors such as running or carrying an object may have been compiled and were added as a second level of information supplementing the first-level type of activities/tasks.

Table 5 Identification of environmental risk factors and type of activity/task in progress at time of accident/incident, for the police officers

Environment	Type of activity/task
• Icy/snowy ground • Uneven terrain, hole, sidewalk/change in level • Stairway/steps • Wet surface • Debris, rocks, or other obstacles on the ground • Change in indoor floor level • Dirty surface • Access ramp • Object, equipment • Inadequate footwear • Poor visibility • Structure, hedge • Furniture • People • Animal • Vehicle • n.s.* When pertinent, the "Environment" item was also detailed in terms of the general location of the event: – inside the police station – outside, near the police station – inside (elsewhere than the police station) – outside (elsewhere than the police station); the lack of visual cues: – darkness – underfoot surface/ground concealing ice under the snow, a hole under the leaves, for example.	• Police intervention o Call/intervention o Complaint o Traffic o Accident o Medical o Crime scene o Foot chase o Training o Physical fitness training o Crowd control o Police intervention n.o.s.** • Other o Arriving at/leaving work o Entering/leaving patrol vehicle/police station o Break/lunch/washroom/meeting o Police event/conference/party o Removing snow/moving a vehicle o Other • n.s.* When pertinent, the "Activity/task" item (first and second levels) was also detailed in terms of the following risk factors: – running or walking fast – carrying objects.

* n.s. = not specified
** n.o.s. = not otherwise specified

Table 6 Identification of environmental risk factors and type of activity/task in progress at time of accident/incident, for the school crossing guards

Environment	Type of activity/task
• Icy/snowy ground • Uneven terrain, hole, sidewalk/change in level • Debris, rocks, or other obstacles on the ground • Objects, equipment • People • Animal • Vehicle • n.s.* When pertinent, the "Environment" item was also detailed in terms of the lack of visual cues: – darkness – underfoot surface/ground concealing ice under the snow, a hole under the leaves, for example.	• School crosswalk activity o Waiting at the intersection o Going to get children o Returning to the intersection after taking children across o Taking children across the street o Being present at the work intersection n.o.s.** • Other than school crosswalk activity o Break o Retrieving a ball o Taking pictures of school children o Outside working hours • n.s.* When pertinent, the "Activity/task" item (first and second levels) was also detailed in terms of: – carrying objects.

* n.s. = not specified
** n.o.s. = not otherwise specified

For nearly two-thirds of the events, more than one environment- or activity/task-related factor may have been involved. Only the factor deemed to be crucial or of key importance in the event was retained in these cases. However, since most of the multi-factorial events involved carrying objects (e.g. a bag or equipment), a foot chase, or a lack of visual cues, these factors were included in the main list of factors as an added detail compounding, or not, the main factor.

2.2.2.3.2 Indicators: frequency, severity, and distribution

Indicators were used in this study to quantify the frequency and severity of the slip accidents (or of STFs, in the case of Appendix B) by gender and age. Frequency was assessed in relation to the annual number of police officers and school crossing guards working in the target organizations (see Table 21, Appendix A). Injury severity was assessed in terms of the average duration of the work absence following an accident with loss of work time. Average duration is a good indicator of injury severity but is not necessarily representative of an average individual. Median absence duration provides information on the central tendency of the injury distribution according to absence duration. In addition, descriptive indicators were produced to situate the event distribution according to time of year, type of accident/incident, and the various risk factors identified. The indicators used were defined as follows:

$$\text{Frequency rate (\%)} = \frac{\textit{(Number of cases of slip accidents (or STFs) in 2007–2009)/3 x 100}}{\textit{Estimated annual number of workers}}$$

Severity in terms of average absence duration (no. of calendar days) =

$$\frac{\textit{Total number of days absent following an accident with time loss in 2007–2009}}{\textit{Total number of cases of slip accidents (or STFs) in 2007–2009}}$$

Severity in terms of median absence duration (no. of calendar days) =

Median number of days absent for accident cases with time loss in 2007–2009, according to a given criterion

$$\text{Distribution (\%)} = \frac{\textit{Number of cases in 2007–2009 according to a given criterion x 100}}{\textit{Total number of cases of slip accidents (or STFs) in 2007–2009}}$$

2.2.3 Focus groups

Focus groups were held as a complement to the literature review and analysis of the accident/incident files in order to gain a better understanding of the relationships among the various risk factors associated with slip accidents. These meetings had a dual purpose: (1) to obtain more details on the characteristics of the accidents experienced by the police officers and school crossing guards, and (2) to determine the particular characteristics of the workers' footwear, often cited as a risk factor associated with slip accidents.

2.2.3.1 Data collection

The participants in these focus groups were municipal police officers, school crossing guards, and highway controllers. The opportunity to include the latter occupational group in this step of the project arose following a suggestion made by one of the follow-up committee's partners. There are in fact similarities between highway controllers and the other occupational groups in terms of both the slip problem and environmental and organizational constraints (outdoor work locations, purchase of boots, etc.). Adding highway controllers to the focus groups allowed the researchers to validate some of the conclusions drawn for the other two groups.

Four meetings were scheduled during the months of January and March 2011: two with police officers, one with school crossing guards, and another with highway controllers. Two types of participants were involved in these focus groups: those who had been victims of slip accidents and those who had not. The reason for proposing these two types of participants was partly to shed light on all ideas and experiences relating to these events, but also to find out whether any equipment or particular strategies existed that could help prevent slips. A total of 39 individuals took part in the focus groups. Table 7 shows the numerical distribution of the participants by occupational group, gender, and involvement or not in a slip accident.

Table 7 Numerical distribution of participants in focus groups

Groups interviewed	Men		Women		Total/group
	No accident	Accident	No accident	Accident	
Police officers, group 1	6	2	2	2	12
Police officers, group 2	4	3	2	1	10
School crossing guards	1		4	4	9
Highway controllers	5	3			8
Total (accident/no accident)	**16**	**8**	**8**	**7**	**39**
Total (men-women)	**24**		**15**		

Each meeting was recorded with the participants' consent. Averaging over two and a half hours in length, the recordings were made because they constituted the primary source of information to be processed by the researchers. A total of four meetings were needed for the study. Two main themes were examined with the focus groups: the description of the accidents or incidents experienced by the police officers, school crossing guards, or highway controllers, and the characteristics of their footwear. Table 8 shows, by theme, the subthemes covered during these semi-structured interviews.

Table 8 Themes and subthemes covered with focus groups

Characteristics of accidents or incidents	**Descriptions of footwear worn**
• Location • Weather conditions • Types of underfoot surface (uneven, sloping, stairway, poorly maintained terrain) • Description of task performed • Work constraint (effort, overexerting, lifting, pushing, pulling, sliding, descending, handling) • Equipment	• Survey of all footwear used by the police officers, school crossing guards, and highway controllers • Description and characteristics of the footwear used by these groups

2.2.3.2 Data analysis

Content analysis was performed as a means of studying the information obtained from the focus groups (Krippendorff, 2003). It required the retranscription of the interviews, followed by use of a grid to code and process all the information obtained from the participants. This analytical grid was not defined at the outset, but rather after listening again to the interview transcripts and reading both the transcripts and the researcher's notes. The interviews were thus coded using an open approach. This made it possible to subsequently identify the passages or phrases related to the specific objectives of this part of the study, namely, to identify various risk factors associated with slip accidents, articulate these relationships, and describe the footwear worn by the police officers and school crossing guards.

More specifically, each phrase or “semantic unit” (Andreani and Conchon, 2001) formed the coding unit for this content analysis. The next step consisted of classifying each of the coding units under various themes such as those related to the risk factors involved in slip accidents. The themes were chosen on the basis of studies (Leclercq, 2003) and fact sheets or guides (APSAM, 2007) dealing with STFs: by reading these materials, the researchers were able to form a clearer idea of how to classify the information collected in the interviews.

3. RESULTS

3.1 Review of the literature

3.1.1 The factors involved in slip accidents and how to prevent them

3.1.1.1 The main risk factor for slip accidents

The main risk factor for slipping is poor grip or low friction between footwear and the underfoot surface (Grönqvist et al., 2001a). Friction is the force that resists the relative motion of solid surfaces, fluid layers, and materials which are in contact with each other. It can therefore be understood as the opposite to "slipperiness." Friction plays a key role in slips and in understanding the falls they can cause. The friction mechanisms at play during walking consist of the interaction between the footwear sole (elastic or viscoelastic), the underfoot surface (often harder), and a contaminant potentially present at the interface between the shoe and floor (Grönqvist et al., 2001a).

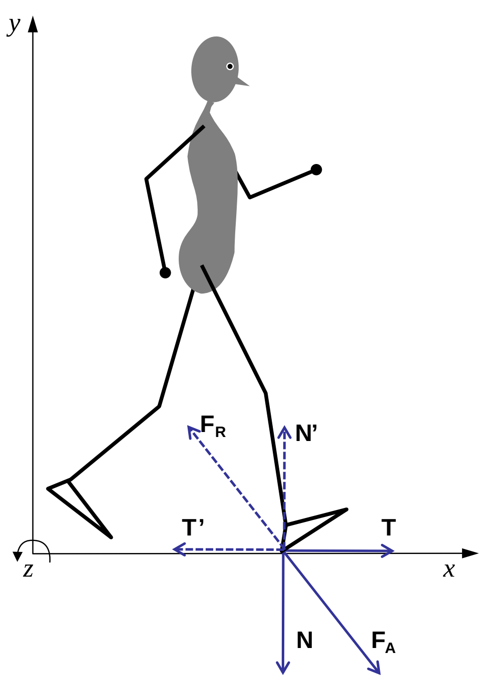


Figure 1 Illustration of forces at shoe/floor interface during heel strike

As soon as the foot touches the floor, the body exerts a force F_A, and an equal but opposite force is applied simultaneously to the body by the floor (F_R), as shown in Figure 1. Forces F_A and F_R each have two components: a tangential (shear) force (T and T' respectively) and a normal force (N and N' respectively). Force T tends to make the foot slip upon heel strike, while T' is the frictional force that opposes the slipping motion. The coefficient of friction (COF) is the ratio of the tangential force to the normal force. The T/N ratio was defined as the "required" COF (Rhoades and Miller, 1988), while the T'/N' ratio was defined as the "available" COF (Strandberg, 1985).

There are two types of friction: static and dynamic. Static friction plays an important role in preventing the initiation of a slip, while dynamic friction determines whether or not a person can recover his[6] balance and avoid injury after starting to slip, or whether or not a slip risks leading to a fall that in turn results in an injury. When the COF between the shoe and the walking surface does not offer enough resistance at the point of contact to neutralize the forward motion force, a slip occurs. A purely mechanical approach suggests that there is no risk of slipping as long as the slipping force does not exceed the static friction limit. The ratio between the normal and

[6] The masculine form is used throughout the text solely in the interests of readability. It refers equally to women and men, with no gender discrimination intended.

horizontal components of the ground reaction forces (GRF) and the relative values of the COF during walking are shown in Figure 2.

A few studies have attempted to quantify the safety threshold for the COF in a variety of activities. Strandberg and Lanshammar (1981) established a limit value of 0.20 for the COF based on the dynamics of the forces exerted at the sole/contact surface interface during walking. They observed that the risk of falling during normal walking was higher at the moment of heel strike, and that the COF ranged from 0.10 to 0.20 when the foot slipped forward without resulting in a fall. They also pointed out that the particular characteristics of the gait (walking speed, stride length, stride width, etc.) influenced the threshold COF. Other values for the safety threshold for the COF have been proposed in the literature. Redfern and Bidanda (1994) and Stevenson (1992) respectively proposed that COF values of 0.50 and 0.40 were needed to prevent falls. However, these values derived more from a mutual consensus than from scientific evidence (Leclercq, 1999). In France, for example, in light of a series of measurements taken for different footwear soles, the Institut national de recherche et de sécurité (INRS) proposed a COF threshold of 0.15 for slip prevention. Strictly speaking, though, this constituted a technical recommendation rather than the establishment of a safety level per se (Tisserand, 1985).

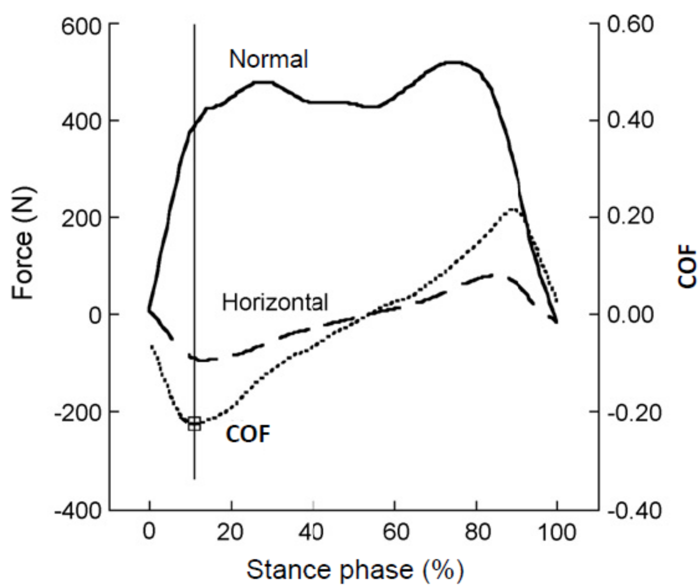


Figure 2 **Example of GRF during the stance phase of the walking cycle. The ratio of the horizontal forces (broken line) to normal forces (solid line) determines the coefficient of friction, or COF (dotted line). The maximum value of the COF at the start of the stride (the vertical line) is defined as the minimum COF required to maintain foot contact stability (adapted from Cooper and Prebeau-Menezes, 2008).**

3.1.1.2 Secondary risk factors for slip accidents

The slipperiness of the footwear/underfoot surface interface cannot alone explain slip and fall accidents. Some secondary risk factors tend to predispose people to accidental injury under slippery conditions or during sudden and unexpected changes in slipperiness. The secondary risk factors for slip accidents involve a variety of extrinsic (organizational and environmental) and intrinsic (physiological and behavioural) factors. The many risk factors and their potential cumulative effects seem to further complicate both slipperiness measurements and the prevention of accidents and injuries caused by slipping.

3.1.1.2.1 Extrinsic risk factors for slip accidents

Extrinsic factors that can cause slip accidents were summarized by Gao and Abeysekera (2004a). They include organizational factors (e.g. activity performed, emergency, or time constraint) and environmental factors (e.g. nature of the ground, use of improper footwear for the ground conditions, sole/ground adaptation, lighting, and temperature).

Taking into account the occupation-related **organizational risk factors**, it appears that the nature of the activity itself can be a cause of falls. When a person is <u>carrying a load</u> while moving, stability can apparently be influenced by the nature, weight, and size of the load, as well as by the person's posture and carrying technique. Bloswick and Love (1991) defined the tendency to slip after heel strike during slow and fast walking. They studied this tendency in load-carrying situations according to gait speed and carrying technique. Heel sliding increased by 27% on average during fast walking compared to slow walking. During walking with a load, the tendency to slide decreased if the load was carried in front of the body but increased if it was carried to the side of the body. Moreover, faster walking velocities could increase the risk of sliding upon heel strike (forward slide) and at toe-off (backward slide), even during walking without load carrying (Tisserand, 1985).

<u>Ascending and descending stairs</u> constitute other demanding and inherently risky tasks that people often perform in their everyday lives. It is believed that a slip between the footwear sole and the surface of steps can play a role in stairway falls (Chang et al., 2004). Nagata (1991) performed a detailed analysis of occupational accidents in stairways. He found that most of the accidents occurred when subjects were rushing down stairs. Time constraints related to emergencies and increased haste on the part of the workers (such as hospital employees, police officers, and others) must therefore be regarded as important etiological risk factors for falls and slips.

With regard to **environmental risk factors,** underfoot surface characteristics have been investigated in many studies. The <u>surface of the road</u> was found to be deficient in over 50% of falls in one such study (Fothergill et al., 1995). The critical factors relate to the dimensions of the contact surface, its smoothness or roughness, and the presence of irregularities (Leclercq, 1997a). The permeability or wear and tear of the flooring, a damaged walking surface (e.g. uneven road pavement, potholes in the road), the presence of obstacles (e.g. construction material, vehicles), and the degree of clutter on the premises appear to be important factors (Bentley and Haslam, 1998). In addition, the <u>presence of a contaminant</u> can lead to falls, depending on its (1) nature (e.g. wet surface, dirt, snow, ice, leaves); (2) type (liquid, solid, or powder); and (3) properties (viscosity, thickness, etc.) (Leclercq, 1997a). Other characteristics of the underfoot surface can also contribute to slip accidents. For example, using an access ramp—a common occurrence in daily life—increases the risk of slips and falls due to the increase in tangential forces along the length of the ramp. This tendency means that ramps pose a particular slip hazard (Redfern and DiPasquale, 1997). The results published in the scientific literature are in line with the popular belief that liquids reduce footwear/ground friction and thus increase the slip risk (Myung and Smith, 1997). Changes in the type of underfoot surface, whether expected or not, could cause postural perturbations and increase the risk of falling.

The use of footwear with soles poorly adapted to the worker's situation ranks among the leading environmental factors contributing to slips. Its role in worker falls has been examined in a few studies (Bruce et al., 1986; Abeysekera et Gao, 2001). Various studies on the slip resistance of footwear have shown the importance of the material, configuration, hardness, and in particular, the tread geometry and worn/unworn condition of the sole in relation to the underfoot surface (Tisserand, 1985). This topic is explored in greater detail in Section 3.1.3 of this report.

Lighting is another major factor in slip accidents, particularly when it is unsuitable for the task, i.e. too bright or too dull. Fothergill et al. (1995) found inadequate street lighting to be a causative factor in 42% of slip accidents in which the victims fell in the darkness. In Canada, the days are shorter in winter, meaning less exposure to daylight. This reduces the visual cues needed to make appropriate postural adjustments, which could be an important causative factor in slip accidents on icy and snowy surfaces. In such cases, much more extensive anti-slip measures are needed to prevent accidents.

Weather too is a risk factor for slips and falls. A study conducted by Bentley and Haslam (1998) found that slip accidents occurred more frequently during winter months and tended to be concentrated on days when there was heavy snowfall or when the formation of ice created hazardous conditions. Cold temperatures affect the slip-resistance properties of footwear soles, yet to date remain a neglected area of research. Moreover, the outdoor temperature acts on the human neuromuscular system (e.g. by cooling down the body), which in turn affects human gait on icy and snowy surfaces (De Koning et al., 1992). Low temperatures appear to increase the risk of falls. In addition, variations in the temperature of icy surfaces modify the COF. On the eastern seaboard of North America and in northerly countries, changing winter weather conditions generate highly variable driving and walking conditions in which surfaces are snowy or covered with melting snow, hard ice, melting ice, or a combination thereof. These natural climate factors increase the prevalence of slips and falls among not only outdoor workers (forestry workers, construction workers, service sector employees, etc.) but also the general population and pedestrians in cold regions (Gao and Abeysekera, 2004a).

3.1.1.2.2 Intrinsic risk factors for slip accidents

The role of intrinsic factors—both physiological (aging, visual functions, pathologies, etc.) and behavioural (experience, attention, fatigue, etc.)—in fall mechanisms was investigated by Gauchard et al. (2001) and Gao and Abeysekera (2004a).

The contribution of various neurosensory inputs to balance control in standing position can vary depending on several factors (including age), and a deficiency in these inputs can perturb balance

(Gao and Abeysekera, 2004a). Elderly people in fact have a poorer capacity to maintain their balance, possibly because their base of support is smaller (Tanaka et al., 1999). They are also less able than younger people to recover their balance when they slip, partly because reflexes slow down with age (English, 1994). Moreover, bone fragility in older people worsens the non-fatal injuries related to falls among this population (English, 1994). The ability to walk safely and maintain one's balance in the event of a slip also depends on the coordination of the visual, proprioceptive, and musculoskeletal systems. Yet all these functions decline with age (Gao and Abeysekera, 2004a). As for the interaction between age and occupation, few studies have found a definite link. Among other publications, one by Kong, Suyama, and Hostler (2013) found that, of all the intrinsic risk factors involved in slip and fall accidents among firefighters, age was not a significant factor.

<u>Visual capacity</u> is an important parameter in the control of walking. Any loss of visual acuity, inadequate lighting, or an inability to discern the environment should all be regarded as possible factors in slips and falls (Gao and Abeysekera, 2004a). People's effective visual field is generally from three to five metres in front of them (Lin et al., 1995). However, if the slipperiness of the walking surface is hard to discern within this effective visual field, or if insufficient time is available to adapt one's gait to the hazardous conditions, the risk of slipping increases considerably (Lin et al., 1995; Gao and Abeysekera, 2004a). Gao and Abeysekera (2004a) found, for example, that more falls occurred on hard, snow-covered ice due to the walker's inability to visually perceive the hidden risk of slipperiness. It follows that any area that is unexpectedly slippery (puddle of water or oil, ice, snow, etc.) can easily cause a slip.

The central processing of postural control allows various neurosensory data to be collected and analyzed, generating a motor response adapted to the situation. This balance function serves to stabilize both gaze and posture (Gauchard et al., 2001). The presence of <u>pathologies</u> altering postural control during data collection and analysis or at the motor level, as for example, in the case of central pathologies of the cerebellum, can cause balance disorders (Gauchard et al., 2001).

A person's <u>lack of experience</u>, that is, unfamiliarity with the work environment, constitutes a major intrinsic risk factor inasmuch as it limits his capacity to adapt to the environment. By contrast, an experienced person who finds himself on a slippery surface can modify the parameters of his gait to move safely on this type of ground (Hanson et al., 1999). Recent studies have shown that slips on ice and snow diminish with experience living in a winter climate (Gao and Abeysekera, 2004b). Other studies have shown that slip training could have beneficial effects on a person's ability to recover his balance and help reduce the risk of slipping (Parijat and Lockhart, 2012; Rich, 2012). The person's <u>attention level</u> also constitutes a significant factor due to its repercussions on the postural adjustments needed to reduce the risk of falling (McIlroy and Maki, 1995).

Motor efficiency depends as well on the capacities of the <u>musculoskeletal system</u>. The reduction in muscle strength with age or illness inhibits certain body movements and limits the balance and coordinated reaction functions, which in turn increases the risks of slipping and falling (Gauchard et al., 2001). <u>Fatigue</u> too can play a role in slip accidents and is a factor that can be deduced from accident data on the times of occurrence and similar inputs (Gauchard et al., 2001).

3.1.1.3 Systematic prevention of slip accidents on icy and snowy surfaces

The complexity of the risk factors involved in slip accidents suggests a degree of interaction among the environmental, organizational, physiological, and behavioural factors. This implies that slip-induced injuries are not the result of innocuous incidents involving basic prevention strategies (Leclercq, 1999). The detection of an environmental factor can potentially help reduce the risk of falls, while the detection of deficient physiological components could lead to specific functional retraining and a strengthening of balance control. Knowledge of extrinsic and intrinsic risk factors reduces the risk of occupational accidents because it allows the work and work environment to be adapted to the worker and the individual's ability to maintain his balance to be optimized. A systematic multi-facetted approach is therefore needed to reduce the incidence of slip-induced injuries. A few researchers, including Abeysekera and Gao (2001), have proposed strategies for preventing or reducing the risk of slip accidents:

- using anti-slip footwear, i.e. properly designed soles (rough and striated with many small treads) made of appropriate material (e.g. nitrile rubber, which is heat- and oil-resistant, or natural rubber);
- perceiving risks so as to be able to adapt one's gait and ensure greater locomotor stability;
- ensuring postural balance while maintaining the body's centre of gravity inside the base of support, and wearing lighter, less cumbersome footwear;
- acquiring the necessary experience to adjust one's gait on slippery surfaces;
- constantly ensuring that stairs and walkways are kept clear of clutter, quickly cleaning up any spills or debris, removing snow and ice, and spreading anti-slip materials such as sand, gravel, or salt;
- adding handrails on stairways or in other appropriate areas; and
- providing adequate lighting to allow for good visibility.

Their conclusions can serve as a stepping stone in the systemic search for an integrated or systematic approach to preventing slip and fall accidents on icy and snowy surfaces.

3.1.2 The mechanics of human movement on slippery surfaces and inclined planes

The biomechanical analysis of slip accidents is a necessary part of prevention research. To avoid a slip-induced fall, the body must take quick and efficient corrective action to recover balance. The biomechanics of postural control strategies, which involve the lower extremity joints and postural adjustments, partly determine the outcome when balance is lost following a slip and therefore play an important role in understanding the complex relationship between locomotion and falls. This knowledge can be used to develop methodologies for measuring slip resistance and to determine critical differences in human behaviour during slips that lead to balance recovery and those resulting in a fall.

3.1.2.1 Biomechanical factors involved in slip and fall accidents

A basic principle in determining the slip risk in any given situation is the relationship between the friction required during locomotion and the friction exerted at the sole/underfoot surface interface. In theory, as long as the available friction exceeds the required friction, the pedestrian does not slip. Ground reaction forces (GRF) at the footwear/underfoot surface interface have been extensively studied and identified as the most critical biomechanical factor in slips (Redfern et al., 2001). The ratio of the tangential (shear) forces to the normal forces of the foot during normal gait on a dry surface, or the friction exerted during slips, is one of the biomechanical variables considered to be most closely associated with the COF measured at the footwear/underfoot surface interface. Different postural situations, including walking on flat ground, carrying a load, and ascending or descending a ramp, require different levels of friction to prevent falls. The biomechanical analysis of gait, in particular by assessing the ground reaction forces, can be extremely useful in reducing slip-induced accidents because it helps identify conditions likely to be hazardous for pedestrians.

One study revealed that the available COF could not be the only critical predictor of falls (Gao and Abeysekera, 2004a). Other biomechanical factors also play an important role in slips, namely, heel impact velocity and the transition of the entire body's centre of mass (COM) during walking on a slippery surface (Redfern et al., 2001). Similarly, the role of the lower extremity muscles in maintaining balance on a slippery surface and in recovering balance after a slip must be taken into consideration. Human responses to balance perturbations caused by slips are often identified by the moments generated in the lower extremity joints and during postural adjustments (Gao and Abeysekera, 2004a).

3.1.2.2 Biomechanics of locomotion and postural control during walking on surfaces of variable slipperiness

This section describes the biomechanical studies of gait on level or inclined surfaces of variable slipperiness. It presents the results of earlier studies on the most important biomechanical factors involved in slips, including GRF, kinematics, and the kinetics of the lower extremity joints during walking on these two types of surfaces.

3.1.2.2.1 Ground reaction forces

Figure 3 shows the normal and anteroposterior (horizontal) forces present during gait on horizontal, non-slippery surfaces (Winter, 1991). Normal force is generally characterized by two peaks. The first peak occurs at the termination of the loading phase (at approximately 25% of the gait cycle) when the body weight is transferred to the supporting foot, while the second peak arrives later in the gait cycle immediately prior to the beginning of the toe-off phase (Winter, 1991; Redfern and DiPasquale, 1997). Anteroposterior shear forces present a symmetrical biphasic waveform, with a first big peak forward (anterior) attributable to the loading dynamics, and with the second peak, which is backward (posterior), occurring when the heel rotates off the ground, pushing back the toes to start the toe-off phase. The first shear force peak is regarded as the most important with regard to slips that result in a fall. It occurs at approximately 19% of the stance phase, that is, between 90 and 150 ms after heel strike, depending on the duration of the gait cycle. As mentioned above, the ratio of the anteroposterior and normal components of the

GRF (i.e. the required COF) is used to quantify the biomechanics of slip accidents during locomotion. The maximum value of this ratio is attained at roughly the same time as the maximum anteroposterior shear force. It is approximately 0.15 for a horizontal surface and more than 0.60 for a surface inclined to 20° (Winter, 1991).

On slippery surfaces, the GRF parameters change due to the postural adjustments required to maintain standing balance while moving forward. In a study aimed at predicting slips based on required friction and available friction during walking, Hanson et al. (1999) found the dynamic measurements of the COF to be higher on dry surfaces than on soapy surfaces (1.43 and 0.16, respectively) for the same type of flooring. These results indicate that the presence of a contaminant on the floor had more impact on the COF than did the actual composition of the flooring. Strandberg (1983) observed that the maximum values of the normal and shear components of the GRF decreased during a slip. He also found that the transfer of body weight to the supporting leg did not appear to be completed during slips resulting in falls. This was evidenced not only in the normal force waveform, but also in the progression of the centre of pressure, which remained near the ankle in the case of falls (Cham and Redfern, 2001). Furthermore, Grönqvist et al. (1993) observed that the average COF during the time on a level, slippery surface was 0.11 (±0.04) in the case of a slip with balance recovery, and 0.04 (±0.02) in the case of a slip resulting in a fall.

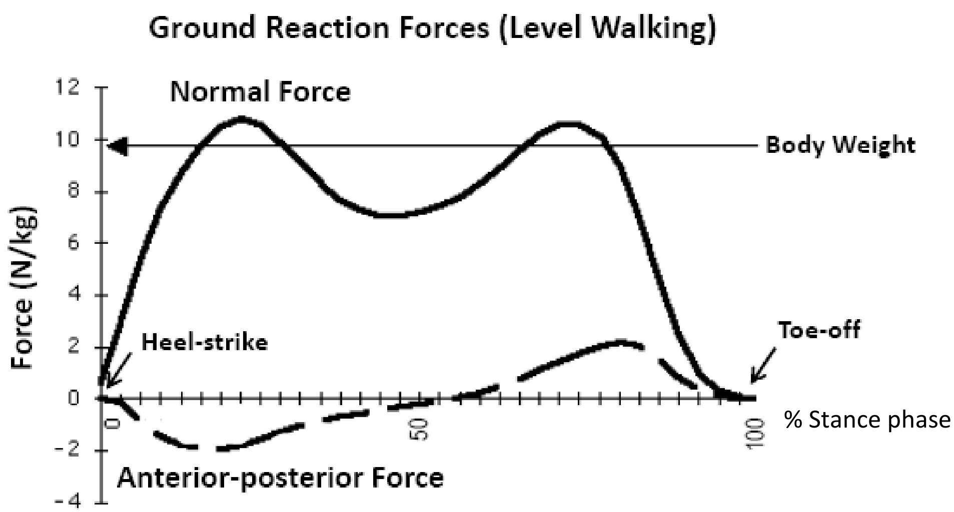


Figure 3 **Normal forces (solid line) and shear forces (broken line) during walking on a horizontal and non-slippery surface, standardized for body weight (adapted from Winter, 1991).**

The GRF on inclined surfaces are not the same as on horizontal surfaces (Redfern and DiPasquale, 1997). In fact, during level walking, the anteroposterior shear forces attain a maximum of 1.5 N/kg during heel strike and –1.5 N/kg during toe-off. During ramp descent, the shear forces increase by nearly 61% for a ramp angle of 5° and by 128% for a ramp angle of 10° (Cham and Redfern, 2002b). During descent of a ramp inclined at 20°, the shear forces increase by 300% (for an average of 4.5 N/kg) at heel strike, and they remain positive during nearly the entire duration of the stride when the ramp angle increases. The moment at which the shear forces attain their maximum on a ramp appears to be the same as during level walking. The increase in shear forces depending on the ramp angle makes slips problematic on inclined planes (Redfern et al., 2001).

3.1.2.2.2 Kinematics of human gait

To assess the kinematics of human gait in the case of slips and falls, the notion of a slip must first be defined from a biomechanical perspective. Redfern et al. (2001) subdivided slips into three categories: microslips, macroslips, and falls. During normal walking on dry, non-slippery surfaces, a heel slip on the floor surface was observed at heel strike and shortly after, followed quickly by complete immobilization. This heel motion, which is imperceptible to the walker, is termed a “microslip” (Perkins, 1978). Based on the distribution of slip distances on dry surfaces or the human perception of slipping, researchers have used cut-off values of 1 cm (Perkins, 1978) or 3 cm (Leamon and Li, 1990), above which values the movement was classified as a “macroslip.” The gap between the cut-off values could be attributable to differences in methodology. Slip distances of more than 10 cm were regarded as corresponding to a full slip, also described as a “fall” (Strandberg, 1983).

A few critical kinematic parameters have been cited as having an impact on slip and fall probability during walking on a variety of surfaces (Cham and Redfern, 2002b). These are gait velocity, step and stride length, heel kinematics (i.e. heel impact velocity), joint angle of the lower limbs, and the kinematics of the upper limbs.

Gait velocity is a parameter that has an effect on the occurrence of slips (Redfern et al., 2001). On a horizontal surface, the average naturally-adopted gait velocity is 1.15 m/s (Sun et al., 1996). A variation in gait velocity can modify the minimum COF required to ensure the stability of the footwear/underfoot surface contact (Grönqvist et al., 2001a). It is commonly acknowledged that slips occur more frequently when a person is walking quickly, changing direction, and ascending or descending a slope, particularly on icy or snowy surfaces. Studies have shown that people change their gait when walking on a slippery surface, notably by slowing down (Gao and Abeysekera, 2004a).

Step length is another determining factor whose impact on the occurrence of slips has been studied, in one instance by Grieve (1983). When step length increases, the ratio of the tangential force to the normal foot force at heel strike is modified such that the tangential force at the start of the stride is increased. A reduction in step length would thus be a way of reducing the risk of slipping when walking. Myung and Smith (1997) observed that stride length was shortened on an oily surface to ensure a more stable posture. When a slip risk is detected using visual or tactile cues (e.g. on an icy walkway), stride length is shortened, which also reduces the speed at which the feet move and the associated tangential forces, such that the body’s centre of gravity is better maintained in the balance zone.

Other researchers have observed that walking on an inclined surface influences certain kinematic parameters. Studies on spatiotemporal and joint kinematics have shown that walking speed, step length, and stride length are reduced as the downhill slope increases (Sun et al., 1996), and that stride length increases as the uphill slope increases (Leroux et al., 2002). The reduction in step length during descent can be explained by the need to reduce friction demand at heel contact in order to prevent a slip (Redfern and DiPasquale, 1997). In fact, during slope descent, friction demand increases due to the effect of the body weight component in play during the descent. A shortened step length reduces this friction demand and thereby, the risk of slips.

Redfern and Bidanda (1994) observed that heel kinematics at heel contact played a role in the risk of slips and falls. Recordings of heel movements in microslip situations (a movement of less than 1 cm) revealed that the heel decelerates quickly prior to heel contact, and that a slight slipping movement then occurs on contact with the walking surface (Cham and Redfern, 2002a). Slip patterns can vary during this phase. Overall, the studies showed that heel velocity (i.e. 0.10 m/s) is exerted in a forward direction immediately after impact, and then either comes to a stop or reverses the direction of the slip before coming to a stop. In all cases cited, this rapid heel motion ended shortly after striking the ground, after which the heel came to a complete stop while the foot continued rotating down on the ground until it was perfectly flat, at about 15% of the walking cycle (Redfern et al., 2001).

The kinematics of the lower extremities (i.e. the joint angles) must also be taken into consideration when studying slips. The kinematics of gait under slippery conditions require certain postural adjustments. In one study where the subjects had no prior knowledge of the slipperiness of a surface, Cham and Redfern (2001) observed that at heel contact and at initiation of the post-contact phase (before 20 to 25% of the gait cycle), the kinematics of the lower extremities on an oily surface were comparable to those on a dry surface, suggesting that no postural adjustment occurred prior to this moment in reaction to a slip. However, at the end of the first third of the gait cycle on an oily surface, tibial rotation was reduced, resulting in plantar flexion of the ankle as well as knee extension. Toward the middle of the gait cycle, a major postural adjustment was observed on an oily surface, particularly with respect to the joint moments of the knee and hip. This attempt at recovery led to an average greater knee flexion of approximately 20°, coinciding with an attempt to bring the foot back towards the body in order to stop the slip. These effects were particularly evident in the case of falls. Based on these results, Cham and Redfern (2001) postulated that the postural reaction consisted of knee flexion and hip extension of the leading leg. The body's corrective reactions on a slippery surface in an attempt to recover balance were evident at about 25% of stance, continuing on until about 45% into stance, i.e. on average between 190 and 350 ms after heel contact.

The foot kinematics at heel contact during descent of an inclined surface were found to be comparable to those when walking on level surfaces (Cham and Redfern, 2002b). When descending a ramp, the foot reached flat-foot position at roughly the same point (at 15% into stance) as on a horizontal surface. Moreover, the slope of the walking surface had the effect of changing the lower extremity joint angles. While changes at the hip and ankle levels were minor, the knee angle underwent a more significant change (Cham and Redfern, 2002b).

3.1.2.2.3 Kinetics of human gait

To avoid a fall after an unexpected dangerous slip, the body has to generate a quick and efficient corrective reaction to recover its dynamic balance while continuing to walk (reactive strategies). Proactive strategies, defined as the balance control mechanisms that occur before the body is subjected to a potential perturbation, can also play a key role in interventions aimed at fall prevention. The theory underlying such an approach, a so-called "system model theory," holds that balance (or equilibrium) does not depend solely on retroactive reflexes (reactive strategies), but also on adaptive motor skills acquired through training and prior experience (Horak et al., 1997). From the perspective of the system model theory, the classification of gait, balance, and mobility as motor skills suggests that deficient postural control can be corrected by targeting proactive strategies in interventions centred on fall prevention.

The joint moments generated as the result of a slip constitute biomechanical reactions aimed at recovering balance. In fact, gait stability is compromised at the initiation of a slip, quickly giving way to efforts to restore balance. This attempt at recovery, sometimes described as a "protective gait strategy," often includes significant differences in lower extremity joint moments compared to walking on non-slippery surfaces (Cham and Redfern, 2001). In addition to identifying a change in knee and hip flexion moments, which is a dominant reaction in slips at between 25 and 45% of stance, Cham and Redfern's study (2001) revealed that the ankle joint played a passive role during trials involving a fall. This can be explained by the proximity of the centre of pressure and the heel, from the beginning to the end of the stance in the case of falls, which indicates an incomplete transfer of weight to the contact foot. In addition, increased knee flexion appears to rotate the shank forward and restore the ankle angle in an effort to bring the foot closer to the body, an effect evidenced in the deceleration of the sliding heel, even in cases of slips resulting in falls (Cham and Redfern, 2001).

The incline of a surface can have a significant effect on lower extremity joint moments. Redfern and DiPasquale (1997) observed considerable variations in hip, knee, and ankle moments during walking on a level surface and walking on an inclined surface. As the ramp angle increased, the knee moments increased and the knee remained extended for longer, the hip moments increased in flexion beyond the first 15% of stance, while the ankle moments varied little, apart from increased dorsiflexion during the first 20% of the stance phase. The moments generated were related to the force and control required to descend a ramp.

In general, when a slip and fall situation is imminent, gait parameters are adjusted so as to maintain an optimal friction demand at the footwear/underfoot surface interface in order to avoid a slip. Gait adjustment also leads to a reduction in friction demand, step length, and heel velocity, as well as a change in muscle activity parameters. The reactive recovery response to a first slip consists of the rapid triggering of a flexor synergy, a major arm elevation strategy, and a modified swing limb trajectory (Marigold and Patla, 2002). The central nervous system adapts quickly following repeated exposure to slippery conditions. Changes were observed within the same slip trial, including the attenuation of muscle response, a reduced braking impulse, and a raising of the body's centre of mass (COM). It was also observed that prior experience with slips made it possible to change the gait, and knowledge of the condition of the walking surface allowed adjustments to be made to negotiate the slippery surface safely (Marigold and Patla, 2002).

3.1.2.3 Postural strategies aimed at fall prevention

Slips have been shown to account for many back injuries, strains, sprains, and fractures (Manning et al., 1988). Postural balance can usually be recovered during a slip through complex neural and motor mechanisms. The latter require sensory information obtained from the visual, vestibular, and proprioceptive systems, as well as adequate organization of the reactions and skills needed to meet the biomechanical demands of sensory stimuli (You et al., 2001).

Most slip events occur unexpectedly. When a slip is initiated, the body tries to recover its balance through a variety of protective responses, as reported by Redfern et al. (2001). Some of these involve the upper extremities, such as using the arms to recover balance or trying to grip onto something, although this latter strategy is only useful if a grabbable support is present. Other responses involve the lower extremities, such as moving the knees, hips, and ankles (Maki and McIlroy, 1997; Cham and Redfern, 2001), but these postural changes do not always offer sufficient fall protection. A compensatory gait response on a slippery surface is thus singularly important and plays an essential role in fall prevention (Redfern et al., 2001).

The relationship between the body's centre of mass (COM) and its base of support has been used to describe the feasible balance control movements. You et al. (2001) studied the kinematics of the body's COM and base of support, more specifically in relation to movement strategies aimed at restoring stability and balance in unexpected slips. They were able to assert that the displacement and velocity of the COM with respect to the base of support were valid predictors of balance conditions in the case of perturbation caused by a slippery surface. In fact, smaller displacement and increased speed of the body's COM with respect to the base of support appear to be a fall prevention strategy used by subjects to recover their balance after heel strike on a slippery surface (You et al., 2001).

Redfern et al. (2001) reported that recovery capacity was probably determined by many factors, particularly those that change the relationship between the body's COM and base of support, such as the motion phase of the slipping foot and length of step of the recovery extremity. However, these factors are difficult to isolate, their individual impacts are difficult to assess, and the cut-off values beyond which a fall cannot be prevented are hard to establish. Knowledge of these factors and their interactions is needed to understand the biomechanics of slip and fall accidents and to evaluate the performance of anti-slip devices on icy and snowy surfaces.

3.1.3 Relationship between footwear and slip accidents

The recommendations formulated in work organizations after they have analyzed slip accidents often include the use of slip-resistant footwear or the installation of a slip-resistant floor covering. These recommendations stress the need for study of the biomechanical and tribological phenomena that occur during a slip in order to identify criteria for assessing the slip resistance of footwear and floor surfaces (Leclercq, 1999).

Slip and fall risks are related to footwear properties (such as the materials used in soling manufacture, the geometric design of the sole, the roughness and hardness of the sole) and floor contamination conditions (Gao and Abeysekera, 2004a), among other factors. In addition, as the topography of footwear and underfoot surfaces can be considerably changed through wear, overall friction behaviour may also be altered such that it may be one of the factors having the greatest influence on slip-resistance properties (Kim, 2004). A surface that initially has a statistically uniform topography could therefore exhibit non-uniform friction properties over time.

3.1.3.1 Friction mechanisms at play in footwear sole/icy surface interaction

All surfaces have some degree of roughness. The variability in surface profiles can be depicted as a random arrangement of peaks and troughs. When two surfaces come into contact with each other, they touch only at the points where their surface asperities meet. In the case of footwear/underfoot surface interaction, the contact is viscoelastic in nature and responds to a reciprocal interlocking mechanism. This mechanism is governed by a number of factors, including the shape, size, and distribution of the asperities in both the footwear sole and the underfoot surface, the properties and condition of the surface, the normal load, and the slip velocity at heel strike.

Gao and Abeysekera (2004a) reported that the majority of slip accidents occur on surfaces covered with snow, ice, grease, or liquid. Their article cites the work of Strandberg (1985) in particular and mentions that "the slip resistance of the lubricated conditions underfoot was dependent at least three different processes:

- the *squeeze-film process*, when the normal force between shoe and flooring displaces a lubricating fluid,
- development of a so-called *hyperesis* component of friction force when sufficient fluid has been displaced to allow draping of the sliding shoe elastomer on the floor asperities, and
- development of a so-called *adhesion* component of friction force due to molecular bonding between the areas of the shoe and flooring surfaces that are in true contact, i.e., where the interfacial fluid has been completely removed." (Gao and Abeysekera, 2004a)

The tribological phenomena that occur at the interface are highly complex (Leclercq, 1999). It is generally acknowledged that friction is caused by adhesion and by the plastic and elastic deformation of the surfaces (hysteresis). If the lubricant is a low-viscous fluid, the surfaces are more or less separated from each other, a factor that considerably reduces the friction. Theories about the presence of water between surfaces focus on the "liquid-like" properties of an icy surface and on the surface formation of water by pressure melting and by melting due to frictional heating (De Koning et al., 1992). These authors posited that it was impossible to say which mechanism caused the low friction on ice. The latest study on friction mechanisms at the footwear/ice interface revealed that little is still known about the properties of the interface layer related to friction on icy and snowy surfaces (Chang et al., 2001a).

Ice is not always slippery. Chang et al. (2001a) reported that the COF of ice can have different values, depending on the ice temperature and walking velocity (e.g. a low COF (< 0.01) at high temperatures (–1 °C) and fast walking velocity (3 m/s), or a high COF (μ = 0.67) at low temperatures (–40 °C) and slow walking velocity. In general, friction during a slip is determined more by the properties of the ice (temperature, structure, and hardness) and thickness of the water layer than by the viscoelastic properties of the polymers (Roberts, 1981). Low hysteresis and low hardness seem to be needed to improve the friction exerted by rubber on ice (Ahagon et al., 1988).

3.1.3.2 Relationship between footwear properties and slip and fall accidents

The important properties of footwear that have been taken into account in studies of their role in slip prevention include the materials used in soling manufacture, tread pattern, and sole hardness and roughness (Gao and Abeysekera, 2004a). These properties are described in greater detail below. Regarding the roughness of the underfoot surface and the reciprocal interlocking of asperities, they are studied mainly to determine the tribological characteristics of footwear and underfoot surfaces and to analyze their influence on anti-slip properties (Kim, 2004).

3.1.3.2.1 Materials used in footwear soles

Bruce et al. (1986) found that the friction values of different types of footwear were generally low on dry icy surfaces at –9 °C compared to other substrates and lower than the values obtained on an oily steel plate. The softest materials produced the highest friction values (0.19 for microcellular polyurethane (PU), 0.17 for soft rubber, and 0.08 for PVC, among others). Gao et al. (2003) reported that PU soles had the greatest slip resistance on oily or wet surfaces. However, other studies have shown that on icy surfaces, the use of soft, thermoplastic rubber-based materials such as nitrile rubber and natural rubber is preferable to PU because these materials are safer on wet icy surfaces (0 °C) and perform better on dry icy surfaces (–10 °C) (Grönqvist and Hirvonen, 1995; Abeysekera and Gao, 2001; Gao and Abeysekera 2004a).

A recent study on the COF of footwear soling (nitrile rubber, double-density PU, thermoplastic PU, styrene rubber, rubber and glass fiber mixture, crepe rubber and microcellular PU on wet ice and on hard ice showed that all materials had a low COF on wet ice (0 °C). Hard ice offered greater slip resistance than a lubricated steel plate. Curling shoes with crepe soles (rubber with a corrugated tread design, called crepe rubber) were those that gave the best results—better even than PU—in terms of slip resistance on hard ice at –10 °C. Crepe rubber was therefore recommended for soling on footwear intended for use on hard ice (Gao et al., 2003).

3.1.3.2.2 Sole shape and tread design

The hypothesis has been advanced that sole shape and tread design affect the slip-resistant properties of footwear on icy surfaces. In a recent study, Liu et al. (2010) observed that the V-shaped tread design of rubber soles did not improve slip resistance in most of the contamination and inclined floor angle conditions tested, regardless of whether the grooves were perpendicular or parallel to the friction measurement direction. However, the underfoot surfaces with molded grooves perpendicular to the friction measurement direction improved slip resistance when contaminants were present (water, glycerol) in most of the soling and inclined floor angle conditions.

Moreover, Li et al. (2006) showed that deep tread grooves improved friction coefficients during walking on slippery surfaces. They measured COFs ranging from 0.018 to 0.108, depending on tread grooves ranging from 1 to 50 mm and on the nature of the underfoot surface and its contamination condition. In another study, Li and Chen (2004) observed that wider tread grooves produced higher COF values during walking on slippery surfaces.

Cleat design was studied in particular by Grönqvist and Hirvonen (1995). Their study showed that flat cleats yielded the highest friction values on dry ice (–10 °C), while sharp cleats yielded the highest friction values on wet ice (0 °C). A recent study by Denbeigh (2013) demonstrated that cleats positioned on sole heels could help prevent slips that occur upon heel contact with an icy surface. However, cleats on the heel only are insufficient to prevent slips on inclined surfaces.

3.1.3.2.3 Sole hardness

Sole hardness is one of the mechanical properties of footwear that can have an effect on friction. Gao and Abeysekera (2004a) reported an increase in the COF values measured on lubricated surfaces in the case of more or less hard soles. However, this increase in friction appeared too small to be of any interest from the safety standpoint. A similar finding was obtained in a cold environment.

Bruce et al. (1986) demonstrated the existence of a negative correlation between sole hardness and COF on icy surfaces (dry ice at –10 °C, $r = -0.876$). In keeping with these results, Grönqvist and Hirvonen (1995) observed a significant negative correlation between kinetic COF and the hardness of the heel material on dry ice (–10 °C). No clear correlation was found, however, on wet ice (0 °C). They concluded that soling hardness accounted for 42 to 53% of the variability in the coefficient of kinetic friction on dry ice, and that increased hardness in the material, if the footwear was kept at –10 °C, reduced the coefficient of kinetic friction on dry ice by 7%. That said, further studies are needed to examine the relationship between hardness and friction under different temperatures in order to determine whether the recommended hardness for footwear designed for use on icy and snowy surfaces applies for all temperatures to which potential users are likely to be exposed.

3.1.3.2.4 Sole roughness (asperity)

Gao and Abeysekera (2004a) reported that sole roughness due to wear appears to contribute to slip resistance. A positive correlation was also observed between sole roughness (average height between peaks and troughs of the asperities) and slip resistance (Figure 4) (Gao et al., 2004; Jung, 1992). Tisserand (1985) demonstrated, however, that soles with asperities reduced slip resistance, and that contrarily, COF values continued to increase as sole smoothness increased.

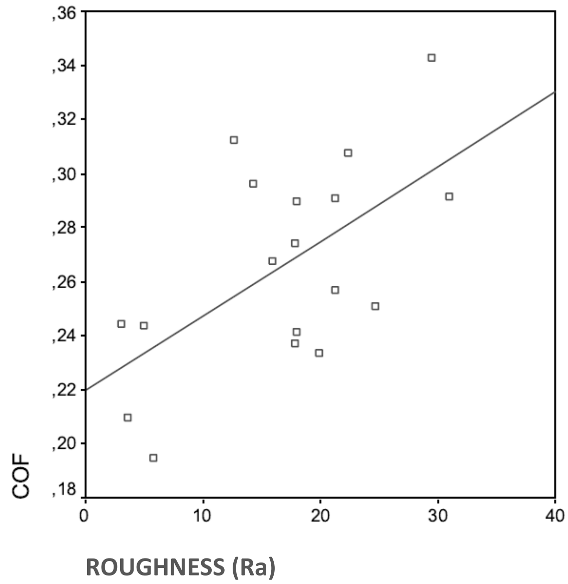


Figure 4 Regression between the COF on ice (–12 °C) and sole roughness (adapted from Gao et al., 2004).

One study which analyzed various types of devices and methods for measuring roughness showed that the roughness of the sole and underfoot surface had a considerable effect on slipperiness (Chang et al., 2001b). The authors also postulated that measuring surface roughness could provide an objective alternative to friction-based methods of measurement. To prevent slips, the average minimum roughness of the elastomer surface must be 5 µm (Leclercq, 1999).

3.1.3.3 Techniques for measuring the COF and slipperiness at the sole/underfoot surface interface

Slipperiness and the COF should be measured in order to determine the slip resistance of footwear on slippery floors. These measurements can be obtained in various ways, usually categorized as follows: human-centered approaches, mechanical measurements of the COF, and COF measurement methods and equipment, as described below.

3.1.3.3.1 Human-centered approaches to measuring slipperiness

Human-centered approaches to quantifying slipperiness include both biomechanical and subjective methods and a combination of the two (Grönqvist et al., 2001b). The main aim of all these approaches to studying traction is to understand what causes slips and how the related accidents could be avoided.

Biomechanical measurements of slipperiness concern the ground reaction forces (GRF), required coefficient of friction (COF), movements of various body segments, joint angles and moments, sliding distances and velocities, and positions of the body's centre of mass (COM) and of the centre of pressure. For example, Hanson et al. (1999) used the ratio between the available and required friction to predict slips. The velocity of heel contact and displacement of the whole body's COM may also be analyzed to assess the likelihood of slip initiation.

Subjective approaches utilize the perception of slipperiness and the perturbation of postural stability to quantify slipperiness by means of ramp trials, paired comparisons, traction trials, and rating scales (Gao and Abeysekera, 2004a). In ramp trials, the angle measurement is used as an indicator of slipperiness: the more pronounced the ramp angle, the slipperier the ramp (Redfern et al., 1998). In paired comparisons, subjects can wear different types of footwear on each foot for purposes of comparison. Manning and Jones (2001) used a traction test bench (fixed and mobile) to measure the COF while the subject was walking backwards on his heels on a slippery surface and pulling on a set of springs fastened to a wall, until losing his balance. The subject was supported by a fall-prevention harness, and the dynamometer was positioned between the belt and the springs. The dynamometer measured the maximum force applied to the springs before the slip, and the COF was calculated by dividing the force applied to the springs by standardized body weight. The last type of subjective measurement used to determine slipperiness at the footwear/underfoot surface interface is the rating scale (perception of slipperiness). For example, Gao and Abeysekera (2002) used a five-point rating scale to assess slipperiness at the footwear/underfoot surface and footwear/ice interfaces. The results showed a significant correlation between the subjective evaluations and the COF measurements. Subjective measurements of slipperiness could therefore be used to verify the anti-slip properties at the sole/underfoot surface interface when direct measurement approaches are not applicable.

3.1.3.3.2 Mechanical measurement of the COF

In addition to biomechanical and subjective sensory tests, a few mechanical devices have been developed to study friction. One of the first attempts to evaluate the slip resistance of footwear was made in France by the INRS, which first proposed using a test bench and a method for evaluating the slip resistance of safety footwear as far back as 1969 (Tisserand, 1969). According to this method, the footwear was placed flat on a stainless steel plate covered with oil, while a vertical force of 600 newtons held the footwear against the surface; at the moment when the measurement was taken, the relative velocity between the oiled surface and the footwear was 0.2 m/s. The measurement conditions were defined in such a way that the measured COF reflected (insofar as possible) the impression of safety experienced by the subjects wearing different types of trial footwear and slipping on an oiled stainless steel plate. A simplified slip model was used to express the requirements in terms of static and dynamic friction. The impressions felt by the subjects revealed that the static COF correlated inversely with their impression of safety, while the dynamic COF and the difference between the two coefficients reflected their feeling of safety. Later studies on the dynamics of the active forces at the footwear/slide surface interface confirmed the pertinence of choosing a dynamic friction index and provided more in-depth knowledge of slips.

A number of other methods and related mechanical devices have also been developed for measuring the COF on floors, whether contaminated or not. Chang et al. (2001b) conducted a survey of all the methods and apparatus for measuring COF both in the field and in the laboratory. However, no single method or apparatus has earned universal recognition with respect to measuring slip resistance, highlighting the need for ongoing research in this area (Leclercq, 1999).

3.1.3.3.3 Methods and materials for measuring the COF on ice

While many methods exist for measuring the COF on dry floors and contaminated or lubricated floors, there are very few for measuring it on icy surfaces. Tisserand (1985) asserted that ice would constitute a difficult and unpredictable surface for testing purposes. Grönqvist and Hirvonen (1995) designed a friction measurement apparatus equipped with a variable-temperature cooling system that allows ice to form on a plate and that can be used to measure the COF at the sole/ice interface in a laboratory. A portable version of this apparatus was developed and validated by Aschan et al. (2004). Like the laboratory version, this apparatus reproduced several parameters of gait kinematics during the critical phase of heel contact. The Aschan et al. (2004) study showed the portable version to be capable of evaluating the slip resistance of footwear in the field and the slipperiness of the underfoot surface in a variety of winter conditions. However, the dynamic COF values obtained for the footwear did not always correlate with the subjects' subjective evaluation of the anti-slip properties. The STM 603 Slip Resistance Testing machine (Wilson, 1990) developed by the research and testing organization SATRA[7] is now designed to allow measurements to be taken on icy surfaces and is used in the new version of the SATRA TM144:2011 test method (Bingham and Rose, 2011). While these new developments hold promise, measuring anti-slip properties on icy or snowy surfaces is not part of current, standardized test methods (CSA Z195-09, 2009; NF EN ISO 13287, 2012). Nor do these methods make it possible to evaluate all winter conditions or the performance of cleated soles. Other studies are therefore needed to improve existing methods.

3.1.4 Summary

The aim of this literature review was to examine the conclusions of prior slip-related studies in order to establish the role of the various risk factors associated with slip accidents and to identify possible preventive courses of action. The following themes were examined:

- causative factors in slip accidents and how to prevent such accidents;
- the mechanics of human movement on slippery surfaces with irregular topography;
- the relationship between footwear and slip accidents.

Slip accidents are caused mainly by insufficient friction at the footwear/underfoot surface interface. However, a number of secondary risk factors can also contribute to causing these accidents, which are multifactorial in nature. Secondary risk factors involve a variety of extrinsic, intrinsic, and mixed factors. Extrinsic risk factors may be environmental (e.g. nature of the underfoot surface, presence of a contaminant, inadequate footwear, temperature, lighting, and visual cues) or organizational (e.g. type of activity being performed, time constraints, carrying a load, going up or down stairs). Intrinsic factors can be physiological (e.g. aging, visual functions, chronic or acute pathologies, capacity of the musculoskeletal system) or behavioural (e.g. experience, attention, fatigue). Better knowledge of these factors is needed if we are to evaluate their impact on the triggering mechanisms of slip accidents and prevent the corresponding risks

[7] http://www.satra.co.uk/portal/

of occupational accidents. Improvements related to environmental, organizational, and behavioural factors could help people who work outside to maintain their balance in various working conditions (e.g. when walking on icy and snowy pedestrian walkways and on level or inclined ground; when pushing, pulling, or carrying loads).

Past studies on the prevention of slips on icy and snowy surfaces have revealed that slip accidents are multi-dimensional and occur under a wide variety of circumstances. Inclusive strategies aimed at reducing slip and fall injuries have been suggested. Using appropriate winter anti-slip footwear, clearing ice and snow off surfaces, improving lighting, keeping stairways and walkways clear and uncluttered, adding handrails, and using walking aids are some of the strategies that could be considered to significantly reduce the risk of slip accidents. Even so, further studies are still needed to determine the relative importance of the various risk factors involved in slips as well as their interactions. Approaches likely to reduce slip-related injuries in workers who perform outside jobs could then be developed.

The biomechanics of slips are an important aspect of injury prevention. An understanding of the biomechanics can help in developing methodologies for measuring slip resistance that reflect the frictional properties of locomotion in real contexts. One of the main determining biomechanical factors in slips has to do with the development of foot forces at heel contact. Measuring the properties of the footwear/underfoot surface interface is essential to ensuring dynamic stability. However, other biomechanical factors present during walking also play a major role in slips; these include foot kinematics at heel contact. For example, a slip of the heel of less than 1.0 cm occurs naturally with nearly every step, without the walker even being aware of it. This slipping of the heel correlates with actual slips of which the walker is aware and with the potentially resulting falls, depending on the length of the slide. Foot movements and forces vary and depend on the walker's state of mind. When a slip risk is perceived, foot forces and kinematics change such that the biomechanics of gait are affected by the walker's perceptions of the environment.

Footwear (sole) characteristics and their interactions with the underfoot surface are among the main factors that affect the friction present between the sole and the surface. The various forms that friction mechanics can take clearly reflect the complexity of the tribological interactions between the sole and underfoot surface. While the current status of theoretical developments regarding footwear/underfoot surface slip mechanisms does not yet allow us to anticipate slip resistance in quantifiable terms based on the known characteristics of a given surface, this literature review may shed some light on the relationship between footwear and slip-induced accidents. The results published to date provide a theoretical basis for understanding friction mechanisms and enhance our grasp of the anti-slip properties of footwear during walking on a slippery surface. They can thus help improve some aspects of footwear and walking surface design so as to reduce the number of slip and fall accidents.

3.2 Descriptive statistics of slip accidents/incidents

3.2.1 Results for the police officers

The analysis presented in this section is limited to slips among the police officers in the three participating police departments during the 2007–2009 period. The results cannot therefore be generalized to all police officers. The slips that occurred among this population during this period represented 55% (301/547) of all STF-related events (see Table 25, Appendix B). In most of these slip accidents/incidents, it was impossible to recover balance and a fall resulted, whether in a stairway (76/301), when getting into/out of a stationary vehicle (26/301), when jumping over or crossing an obstacle (6/301), or any in other situations (166/301) (Table 25). Appendix B presents a succinct analysis of all the STF events that occurred among the police officers.

3.2.1.1 Frequency and severity of the slips, by gender, age, and date of event

The number of slip accidents/incidents was compiled for all the police officers in the three participating organizations. The annual frequency of slips among the officers on duty, as well as the severity of the slip accidents involving loss of work time that occurred in 2007–2009, are presented by gender in Table 9 and by age in Table 10.

Table 9 Frequency (a) and severity (b) of slips among the police officers in the three departments studied, by gender, during the 2007–2009 period

a) Annual frequency of slips, with and without loss of work time

Gender	Average no. of workers/yr.	Average no. of slips/yr.	%
F	2,476 (24%)	34.7 (35%)	**1.4**
M	7,789 (76%)	65.7 (65%)	**0.8**
TOTAL	10,265 (100%)	100.3 (100%)	**1.0**

b) Severity of slip accidents involving loss of work time that occurred during the three-year period

Gender	No. of accidents with loss of work time	Average absence duration [days]	Median absence duration [days]
F	29	83.6	21.0
M	73	52.9	20.0
TOTAL	**102**	**61.6**	**20.5**

Table 10 Frequency (a) and severity (b) of slips among the police officers in the three departments studied, by age, during the 2007–2009 period

a) Annual frequency of slips, with and without loss of work time

Age	Average no. of workers/yr.	Average no. of slips/yr.	%
18-34	3,851 (38%)	51.0 (49%)	**1.3**
35-44	3,872 (38%)	30.3 (32%)	**0.8**
45+	2,542 (25%)	19.0 (19%)	**0.7**
TOTAL	10,265 (100%)	100.3 (100%)	**1.0**

b) Severity of slip accidents involving loss of work time that occurred during the three-year period

Age	No. of accidents with loss of work time	No. of accidents with loss of work time	Median absence duration [days]
18-34	38	47.3	18.0
35-44	40	72.1	23.5
45+	24	66.9	21.0
TOTAL	**102**	**61.6**	**20.5**

Slip accidents/incidents occurred among approximately 1.0% of the police officers annually during the 2007–2009 period, according to the data collected. Accidents involving loss of work time represented nearly 34% (102/301) of all the slip accidents among the officers (see Table 4).

These accidents resulted in an average absence duration of 61.6 days and a median absence duration of 20.5 days (Table 9b and Table 10b).

Slips were more frequent among the women, involving 1.4% of them compared to 0.8% of the men (Table 9a). This result followed the same tendency as that observed in our analysis of the CSST data on STFs among all Québec workers (Prud'homme et al., 2012). Regarding the severity of accidents involving loss of work time, the average absence duration among women was 30.7 days longer than that for men due to the greater severity of some serious cases occurring among the women.

Young officers under age 35 in the three departments appear to be those most affected by this problem. In fact, while this age group represented only 38% of the officers, it accounted for 49% of the workers affected annually (Table 10). However, it appears that age influences the severity of the accidents involving loss of work time. The average absence duration rose from 47.3 days for the police officers in the 18- to 34-year age group to over 65 days for those in the 35 years and over age group. Similarly, the median absence duration rose from 18 days for those in the 18- to 34-year age group to 21 days for those ages 35 years and over. Again, the tendency observed here is similar to that seen in our analysis of CSST data on STFs among all Québec workers (Prud'homme et al., 2012).

Figure 5 shows the number of slips that occurred during the 2007–2009 period among the police officers, by month of the year. Slip frequency was higher during the winter months. In fact, December, January, February, and March accounted for 80% of the cases. The same tendency was observed in all three police departments studied.

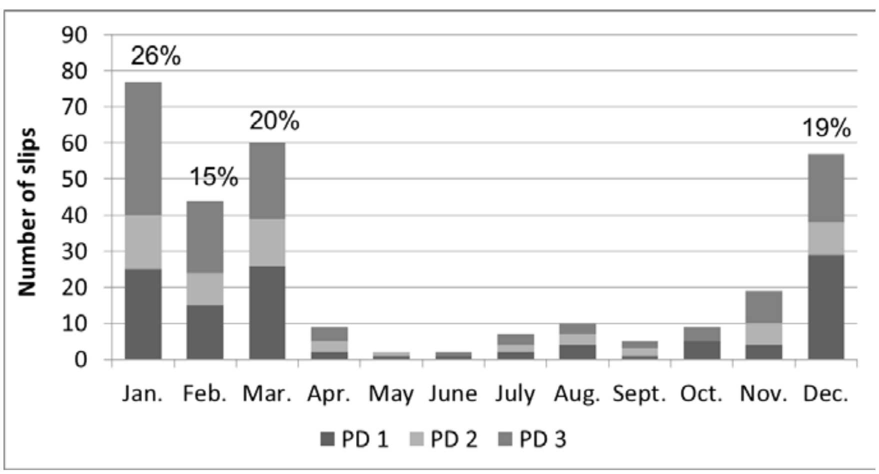


Figure 5 Distribution of number of slips that occurred among the police officers in the three police departments studied, by month of the year, during the 2007–2009 period

3.2.1.2 Distribution of slips by various extrinsic risk factors

Statistical analysis of all the data by environmental risk factor and type of activity/task being performed at the moment of the event allowed us to qualify the magnitude of the various factors. The results are presented in this section in the form of highlights that emerged during analysis.

3.2.1.2.1 Activities/tasks

Generally speaking, for all accidents/incidents combined, 60% of the slips (182/301) occurred during **police interventions** (Table 11). These interventions by patrol officers usually involved responding to calls (112 cases). The other types of intervention consisted mainly of foot chases (17 cases), traffic assignments (13 cases), and responding to complaints (13 cases).

Table 11 Distribution of slips, by type of activity/task and type of accident/incident, among the police officers during the 2007–2009 period

Type of accident/incident	General slip with/without fall				Slip in a STAIRWAY or on steps			Slip getting into/out of a stationary VÉHICLE			Slip when JUMPING over or CROSSING… …			Aggregate TOTAL
Type of activity/task	-	Running	Carrying objects	TOTAL	-	Carrying objects	TOTAL	-	Carrying objects	TOTAL	-	Running	TOTAL	
Police intervention	**76**	**23**	**4**	**103**	**59**	**1**	**60**	**12**	**2**	**14**	**4**	**1**	**5**	**182**
Call/intervention	45	5	3	53	46	1	47	7	1	8	3	1	4	112
Foot chase		17		17										17
Complaint	4	1		5	8		8							13
Traffic	12			12					1	1				13
Accident	8			8				2		2	1		1	11
Police activity n.o.s.*	5			5	3		3	1		1				9
Crime scene	1			1				2		2				3
Medical			1	1	2		2							3
Crowd control	1			1										1
Other	**77**		**7**	**84**	**5**	**1**	**6**	**11**	**1**	**12**	**1**		**1**	**103**
Entering/exiting patrol vehicle/police station	44		4	48	5	1	6	9		9				63
Arriving at/leaving work	9		3	12				2	1	3				15
Training	7			7										7
Other	5			5										5
Break/lunch/washroom/meeting	4			4							1		1	5
Removing snow/ moving vehicle	5			5										5
Physical fitness training	2			2										2
Police event/conference/party	1			1										1
Activity not specified	**6**			**6**	**10**		**10**							**16**
Aggregate TOTAL	**159**	**23**	**11**	**193**	**74**	**2**	**76**	**23**	**3**	**26**	**5**	**1**	**6**	**301**

* n.o.s. = not otherwise specified

A significant proportion of the slips—34% (103/301)—also occurred during **other activities,** which, however, would seem to require less attention or demand fewer interactions with the public (Table 11). These activities may involve, for example, entering or leaving the police station, getting into or out of a patrol vehicle (63 cases), and arriving at or leaving work (15 cases). This significant proportion of cases occurring during other activities was particularly applicable to accidents/incidents in the 'General slip with/without fall' (44%, 84/193) and 'Slip getting into/out of a vehicle' (46%, 12/26) categories.

Running was a risk factor in 8% of the slips (a total of 24/301 cases) (Table 11). During police interventions, this factor came into play in 13% of the cases (24/182), mostly during foot chases. In a study conducted by the SPVM's joint committee[8], 23% of the events related to all STFs occurred when running. Lastly, 5% of the cases occurred **when carrying an object** (a total of 16/301 cases) (Table 11). These percentages may, however, be considered relatively low, especially as they do not exceed, or only minimally exceed, the percentage for unspecified cases (5%, 16/301) and for which the description was insufficiently detailed to identify a possible activity-related factor.

3.2.1.2.2 Environment

The most frequent environmental risk factor among the police officers was **icy/snowy ground**. It was a factor in 72% (217/301) of all slip accidents/incidents (Table 12). The ground was usually covered with ice (200/217, 92%) or snow (17/217). In 22% of the slips on icy/snowy ground (a total of 48/217 cases), the description said that the worker **had not seen the ice**, usually because it was hidden under snow and in a few cases because it was dark. Icy/snowy ground was a particularly frequent factor in the 'General slip with/without fall' (85% of the cases, 165/193) and 'Slip getting into/out of stationary vehicle' (88% of the cases, 23/26) types of accidents/incidents.

Overall, 85% of the slips occurred **outside** (a total of 256/301 cases, Table 12), most on roads, in parking lots, or on sidewalks located in residential or industrial areas. Of this number, 28% occurred **near the police station** (71/256). These cases were relatively numerous in the 'General slip with/without fall' type of accident/incident category where icy/snowy ground was a factor: 37% of these slips occurred near the police station (61/165), i.e. in the parking lots (39/61) or on the walkways leading to the station (22/61).

The second most frequent environmental risk factors in slips were "**wet surface** and **stairway or steps**," particularly present in the 'Slip in a stairway or on steps' category (Table 12). Slips in a stairway accounted for 25% of all the slips (76/301). For this type of accident/incident, the most common environmental factors were a wet surface (29/76), an icy/snowy surface (27/76), and the stairway itself (19/76), which represented 38%, 36%, and 25% of the cases respectively (Table 13). For a certain number of cases (17/76) classified as having occurred 'In a stairway or on steps,' the causative factor in the event was not specified. The typical description was simply 'I slipped on the stairs.'

[8] SPVM – Service de police de la Ville de Montréal, 2010. Joint-committee section (occupational health and safety). Personal communication.

Table 12 Distribution of slips, by environmental risk factor and type of accident/incident, among the police officers in the three departments studied during the 2007–2009 period

Type of accident/incident	General slip with/without fall			Slip in a STAIRWAY or on steps			Slip getting into/out of a stationary VÉHICLE			Slip when JUMPING over or CROSSING… …			Aggregate TOTAL
Environment General location	-	Didn't see the ground	**TOTAL**	-	Didn't see the ground	**TOTAL**	-	Didn't see the ground	TOTAL	-	Didn't see the ground	**TOTAL**	
Icy/snowy ground	**126**	**39**	**165**	**25**	**2**	**27**	**17**	**6**	**23**	**1**	**1**	**2**	**217**
Various outdoor locations	*79*	*25*	*104*	*21*	*2*	*23*	*16*	*5*	*21*	*1*	*1*	*2*	*150*
Near the police station	*47*	*14*	*61*	*4*		*4*	*1*	*1*	*2*				*67*
Wet surface	**8**	**1**	**9**	**29**		**29**	**1**		**1**				**39**
Various outdoor locations	*1*	*1*	*2*	*10*		*10*							*12*
Near the police station	*1*		*1*				*1*		*1*				*2*
Various indoor locations	*1*		*1*	*15*		*15*							*16*
Inside the police station	*5*		*5*										*5*
*n.s**				4		4							4
Stairway/steps				**19**		**19**	**2**		**2**				**21**
Various outdoor locations				*3*		*3*	*2*		*2*				*5*
Near the police station				*1*		*1*							*1*
Various indoor locations				*9*		*9*							*9*
Outside the police station				*1*		*1*							*1*
n.s.				*5*		*5*							*5*
Uneven ground/sidewalk/change in level	**11**		**11**							**3**		**3**	**14**
Various outdoor locations	*10*		*10*							*3*		*3*	*13*
Near the police station	*1*		*1*										*1*
Dirty surface	**1**		**1**	**1**		**1**							**2**
Debris, rocks, etc. on the ground		**1**	**1**										**1**
Animal	**1**		**1**										**1**
Structure, hedge										**1**		**1**	**1**
Environment not specified	**5**		**5**										**5**
Aggregate TOTAL	**152**	**41**	**193**	**74**	**2**	**76**	**20**	**6**	**26**	**5**	**1**	**6**	**301**

* n.s. = not specified

Generally speaking, 54% of the slips in a stairway (41/76, Table 13) occurred outside, and nearly two-thirds of these on icy/snowy steps (27 cases). In 34% of the cases (26/76), the slips occurred inside. On indoor stairways or steps, more than half of the slips (15 cases) occurred on wet steps, mostly because of footwear (boots or overshoes) that was wet due to rain or snow.

Despite the often insufficiently detailed event descriptions, it appears that slips in stairways occurred more frequently descending than ascending. Of the 76 documented cases of slips in a stairway or on steps, 51 cases (67%) occurred going down the stairs and one case going up. In the other 23 cases (30%), it was impossible to know.

Table 13 Distribution of number of *slips in a stairway or on steps*, by main environmental factor, among the police officers in the three departments studied during the 2007–2009 period

Environment	Slip in a STAIRWAY or on steps			
	Outside	Inside	Not specified	TOTAL
Wet surface	**10**	**15**	**4**	**29**
Icy/snowy surface	**27**			**27**
Stairway/steps	**4**	**10**	**5**	**19**
Stairway, steps (not otherwise specified)	*4*	*9*	*4*	*17*
Carrying an object		*1*		*1*
Defective handrail			*1*	*1*
Dirty surface		**1**		**1**
TOTAL	**41**	**26**	**9**	**76**

3.2.2 Results for the school crossing guards

The analysis presented in this section is limited to slips among the school crossing guards in the two cities studied, during the 2007–2009 period for City 1 and the 2008–2010 period for City 2. The results cannot therefore be generalized to all school crossing guards. Table 31 in Appendix B shows that slips represented 45% (28/62) of all the STF-related events among the guards during the study period. In the majority of cases, balance could not be recovered and a fall ensued (24/28, Table 31). Appendix B provides a succinct analysis of all the STF events that occurred among this population.

3.2.2.1 Frequency and severity of slips, by gender, age, and date of event

The number of slip events was compiled for the school crossing guards in the two cities studied. The annual frequency of slips relative to the number of crossing guards on the job, as well as the severity of the cases involving loss of work time that occurred during the three-year period, are presented by gender in Table 14 and by age in Table 15.

Table 14 Frequency (a) and severity (b) of slips among the school crossing guards in the two cities studied, by gender, during a three-year period (2007–2009 for City 1 and 2008–2010 for City 2)

a) Annual frequency of slips, with and without loss of work time

Gender	Average no. of workers/yr.	Average no. of slips/yr.	%
F	597 (63%)	8.3 (89%)	**1.4**
M	352 (37%)	1.0 (11%)	**0.3**
TOTAL	949 (100%)	9.3 (100%)	**1.0**

b) Severity of slip accidents involving loss of work time that occurred during the three-year period

Gender	No. of accidents with loss of work time	Average absence duration [days]	Median absence duration [days]
F	13	118.8	9.0
M	2	26 and 84	-
TOTAL	**15**	**110.3**	**19.0**

Table 15 Frequency (a) and severity (b) of slips among the school crossing guards in the two cities studied, by age, during a three-year period (2007–2009 for City 1 and 2008–2010 for City 2)

a) Annual frequency of slips, with and without loss of work time

Age	Average no. of workers/yr.	Average no. of slips/yr.	%
18-59	471 (50%)	6.7 (71%)	**1.4**
60+	478 (50%)	2.7 (29%)	**0.6**
TOTAL	949 (100%)	9.3 (100%)	**1.0**

b) Severity of slip accidents involving loss of work time that occurred during the three-year period

Age	No. of accidents with loss of work time	No. of accidents with loss of work time	Median absence duration [days]
18-59	12	122.3	14.0
60+	3	62.3	47.0
TOTAL	**15**	**110.3**	**19.0**

Over a three-year period, 1.0% of the school crossing guards in the two cities studied were involved annually in a slip accident/incident, according to the data collected. Accidents involving loss of work time represented nearly 54% (15/28) of all the slips among the crossing guards (see Table 4). These accidents resulted in an average absence duration of 110.3 days and a median absence duration of 19.0 days (Table 14b and Table 15b).

More slips occurred among women, proportionally speaking, for the period concerned in the two cities studied. In fact, 1.4% of the women were affected compared to only 0.3% of the men. With regard to age, it was the school crossing guards in the 59 years and under age group who were more frequently involved in slips (1.4%) than those ages 60 years and over (0.6%). While the number of cases was low and possibly varied from year to year, these results follow the same tendency as that observed in our analysis of CSST data for STFs among all Québec workers (Prud'homme et al., 2012).

It was difficult to discern a tendency in the severity of the accidents involving loss of work time by age group or gender because the number of events over the three-year period was too small. In addition, two cases out of the 15 accidents analyzed had a particularly high absence duration of 448 and 776 days respectively (two women ages 59 and under).

Figure 6 shows the number of slips that occurred among the school crossing guards, by month of the year, for the 2007–2009 period for City 1 and the 2008–2010 period for City 2. Event frequency was higher in the winter months. It was particularly high during the month of December (29% of the cases), even though it includes fewer weeks of activity than other months of the school year, and during the month of March (25% of the cases).

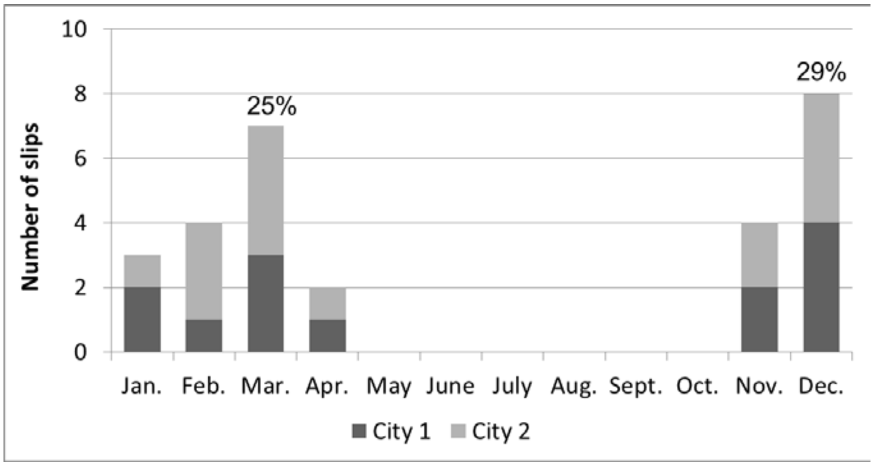


Figure 6 **Distribution of number of slips that occurred among the school crossing guards in the two cities studied, by month of the year, during a three-year period (2007–2009 for City 1 and 2008–2010 for City 2)**

3.2.2.2 Distribution of slips by various extrinsic risk factors

Analysis of all the slip accidents/incidents made it possible to characterize the various environmental risk factors and types of activity/task being performed at the moment of the event. The highlights of this analysis are presented in this section.

3.2.2.2.1 Activities/tasks

Most of the slips (89%, 25/28 cases) occurred during a school crosswalk activity (Table 16). However, the descriptions of these events were limited. It was only possible to ascertain whether the event occurred when taking children across the road (6 cases), going to get children (2 cases), or returning to the intersection after taking children across (1 case). In 16 cases, no additional detail was mentioned other than the fact that the school crossing guard was at the intersection when the event occurred. A few slips (3 cases) occurred during activities other than taking children across the road (Table 16).

Table 16 **Distribution of slips, by type of activity/task, among the school crossing guards in the two cities, during a three-year period (2007–2009 for City 1 and 2008–2010 for City 2)**

Type of accident/incident / Type of activity/task	General slip with/without fall
School crosswalk activity	**25**
Present at the intersection, not otherwise specified	16
Taking children across the road	6
Going to get children	2
Returning to the intersection after taking children across	1
Other activity	**3**
Outside working hours	2
Break	1
Aggregate TOTAL	**28**

3.2.2.2.2 Environment

Icy/snowy ground was the main environmental risk factor in slips among the school crossing guards (Table 17) for the two cities studied. It was involved in 27 of the 28 slip events. In 28% of the cases (8/28), the description said that the guard **had not seen the ice** because it was hidden under the snow. In most cases, it said that snow had not been cleared off the road or sidewalks or that they had been cleared but the surface remained slippery and no abrasive had been spread.

Table 17 Distribution of slips, by environmental risk factor and type of activity/task, among the school crossing guards in two cities, during a three-year period (2007–2009 for City 1 and 2008–2010 for City 2)

Type of accident/incident / Environment / Type of activity/task / *General location*	General slip with/without fall		
	-	Didn't see the ground	TOTAL
Icy/snowy ground	**19**	**8**	**27**
School crosswalk activity	17	7	24
Walking on the road or sidewalk	*14*	*7*	*21*
Stepping off the sidewalk	*3*		*3*
Other than school crosswalk activity	2	1	3
Environment not specified School crosswalk activity	**1**		**1**
Aggregate TOTAL	**20**	**8**	**28**

3.2.3 Summary

In the organizations studied over a three-year period, slip accidents/incidents occurred among 1.0% of the police officers and 1.0% of the school crossing guards annually. The average absence duration of accidents involving loss of work time was 61.6 days for the police officers (median absence duration of 20.5 days) and 110.3 days for the school crossing guards (median absence duration of 19.0 days).

Slips occurred more frequently among the women than the men in both groups. Among the police officers, the age group most frequently affected by this problem was the 18- to 34-year olds, but accident severity was greater in the 35 years and over age group. Among the school crossing guards, the 59 years and over age group was the most frequently affected, but no tendency could be seen regarding accident severity. Slips occurred more frequently during the winter months in both populations.

For police officers, the most frequent environmental risk factors were:

- **Icy/snowy ground**, which caused 72% of the slips (217/301). This factor was especially significant in general slips with/without a fall (85% of the cases, 165/193) and slips getting into/out of a stationary vehicle (88% of the cases, 23/26).
- **Icy/snowy parking lots and walkways near the police station,** which accounted for 37% of the general slips with/without a fall where icy/snowy ground was a factor (61/165). For all accident/incident types combined, slips near the police station accounted for 28% of the cases occurring outside (71/256).

- For slips in a **stairway** (this type of accident/incident accounted for 25% of all slips), the most common environmental factors were a wet surface (38% of the cases, 29/76), an icy/snowy surface (36%, 27/76), and the stairway itself (25%, 19/76).
- The **lack of visual cues** factor was also significant. It caused 22% of the slips on an icy/snowy surface (48/217), where the ice was not visible usually because it was covered with snow.

Also among the police officers, the most frequent activities/tasks involving slips were:

- all types of **police interventions**, particularly calls (on patrol), which represented 60% (182/301) of all the cases;
- **other activities** requiring fewer interactions with the public, for example, entering or leaving the police station, getting into/out of the patrol vehicle, or arriving at/leaving work, also appear to pose some risk since they were being performed during the event in 34% (103/301) of the cases;
- **running**, mainly during foot chases, which was involved in 8% of all the slips (24/301).
- **carrying objects,** which was factor in 5% of all the slips (16/301).

For the school crossing guards, the most frequent secondary environmental risk factor was **icy/snowy ground**, which was present in most of the slips (27/28). A **lack of visual cues** was also a factor in 28% of the cases (8/28) where the ice was hidden under the snow.

Poor maintenance of the road and sidewalks at the intersection was also a significant factor. In fact, in most of the slips, the snow had not been cleared from the road or sidewalks, or had been cleared but the surface was still slippery and no abrasive had been spread. This is an organizational factor and will be examined in Section 3.3.2.

The type of activity/task most frequently being performed during the event was obviously the **school crosswalk activity** (89% of the cases, 25/28).

3.3 Focus groups

In order to clarify some of the risk factors involved in slips, gain a better understanding of the relationships among these factors, and identify the particular features of the work footwear used, 22 police officers and nine school crossing guards were met in focus groups, along with eight highway controllers as they face similar working conditions to police officers.

3.3.1 Factors influencing slips according to participants

A number of factors were often cited by the police officers, school crossing guards, and highway controllers as influencing the risk of slips in their jobs. These factors pertain to both how the work is organized and the work environment.

In terms of how the work is organized, the police officers, school crossing guards, and highway controllers all mentioned their equipment (mainly footwear) and tasks as factors. In the case of footwear, the police officers and highway controllers cited problems in finding "appropriate boots for their activities[9]." These constraints were aggravated for workers who had difficulty "finding footwear in their size." According to the participants, they cannot obtain small-size (smaller than size 7) or large-size (bigger than size 12) boots or half sizes from the official suppliers: "There's no size 9.5 for me; it's either 9 or 10." To minimize the problem, some police officers and highway controllers insert "a sock or insole to compensate, but it doesn't do the trick." In addition, all the police officers interviewed stated as follows: "we don't have the opportunity to try on several models; we just choose a model on the Internet" or "they ask us to come to the office one day to try on a boot and that's it." The choice thus appears to be limited and sometimes the footwear design is not suitable. "It's too narrow and it really hurts my foot (…) that's since the brand changed, and between my winter and summer Gore-Tex boots, it's just not the same thing anymore." Boot comfort was also cited as a risk factor, in the following terms: "they're not warm enough in winter, and personally, when I've got cold feet, I'm more at risk of falling because my feet are frozen."

In addition, various remarks made by the police officers and highway controllers suggested that some boots exist that are better than others. The police officers observed this when, for example, they compared their equipment to that of co-workers on SWAT[10] teams: "I was able to get hold of some SWAT winter boots and they're really a lot better (…) the sole is softer, lighter, and less slippery." What the other participants felt was often expressed in this way: "We have winter boots with very high and very heavy soles that are extremely slippery." This is compounded by the fact that, according to the participants, police officers and highway controllers do not have any technical or scientific documents telling them which boots are best adapted to their tasks.

Other examples also illustrate the fact that the footwear ordering system can be a constraint when obtaining this equipment. Some police officers said they do not have enough points[11] to order their winter (or summer) boots, and in some cases, they may find themselves wearing "summer Gore-Tex" boots in winter (and vice versa). Other examples underscore how long they have to wait for the orders. For example, the police officers have to choose their winter boots on their website in February, but may only receive them at the end of September or in early October. However, in some instances, the size no longer fits: in fact, "the size 10 of one summer footwear company is not necessarily the same as a size 10 from another company that supplies the winter footwear." The worker then has to place a new order and wait again to obtain his boots. Other constraints related to footwear stocks can also exacerbate the ordering problem because the worker might not be able to obtain the footwear ordered or may have to wait a few months before receiving it.

[9] The phrases in quotation marks are translations of the French wording used by the participants.

[10] SWAT (Special Weapons and Tactics) teams are from a specialized unit within a police force that carries out paramilitary operations in big cities.

[11] Orders for footwear or equipment such as pants, jackets, or shirts are placed using points that workers receive when they start working and are renewable from year to year.

The system for accessing winter footwear is completely different for the school crossing guards. They have to purchase their boots themselves and then apply to be reimbursed. It also appears that school crossing guards do not have “much money to buy a good winter boot (. . .) because the best often cost over $200, and I don’t want to spend that much; I’d rather wear cleats.” In fact, a large number of the guards wear anti-slip sole attachments (Figure 7) to avoid slips. These attachments are provided free of charge to the crossing guards because “they are considered safety equipment.” However, they have their drawbacks, as evidenced in the discussions: “They are too soft and they move around on your boots,” “they don’t work, they make me slide, and they don’t grip the ice.”

Figure 7 Example of anti-slip sole attachments

The highway controllers, somewhat like the school crossing guards, receive a reimbursement for the purchase of their summer footwear and winter boots, which they too must obtain themselves from suppliers offering CSA-certified equipment.

The other factors often blamed by the participants include their tasks. The main risk factors cited by the school crossing guards were “going to get a child who has stepped into the road too quickly,” or having “to stop the traffic quickly by straddling a snow bank,” having to tell motorists about their lack of courtesy such as when “they disobey the 50 km/h speed limit” or “when they don’t even stop.” The absence of cleared sidewalks is another factor, as expressed by one guard: “I arrived in the morning, and the people from the city hadn’t even cleared my street and I fell at the intersection because there was a hole I didn’t see.”

The risk factors most frequently cited by the police officers and sometimes the highway controllers were as follows:

- handling a load, particularly “when you have to go to the parking lot carrying your equipment (from 15 to 20 kg); sometimes it’s heavy and you can fall on a patch of black ice near the car or even near the door (...); that’s what happened to one of my co-workers”;

- chasing a suspect who’s not obeying an order, described as follows: “I had to run into the garden to catch him, but I didn’t see the fence under the snow and I fell,” or “I had someone who was moving all the time when I stopped him and I slipped on the ice,” or again “I stepped into a hole that was hidden under a snow bank (...) behind the suspect’s house”;

- getting out of a vehicle for any intervention (highway control, arrest) was also emphasized as, for example, when getting out “I didn’t pay attention to the patch of ice” or “I was nice and warm inside the vehicle, but when I got out, I twisted my ankle and fell”;

- traffic, for example, “at a crossroads, I had to stop the cars and help someone cross and I fell down.”

Other factors related to the work environment were also cited by the police officers, highway controllers, and school crossing guards as being likely to have an influence on falls. One of the most frequently discussed was, of course, weather conditions, particularly during winter. Understandably, ice and snow are the main factors likely to cause these workers to fall or slip. Slip accidents are the result of patches of black ice, or are related to holes, inclines, stairways, changes in level (stairs covered with ice and snow, for example), or obstacles hidden under snow. While few slip accidents occurred during the summer, the police officers and highway controllers said that any such accidents were caused by their footwear: “too heavy,” “the sole doesn’t really grip because they’re my winter boots, and the sole is too rigid,” or “I didn’t manage to get my summer boots; I was walking with my winter Gore-Tex and I fell because they were too heavy for my feet.”

The police officers, school crossing guards, and highway controllers also said they had insufficient training to prepare them to avoid risky situations and hence potential accidents: “the CSST documents don’t cover everything,” “we have information meetings at the end of August or early September, and they just tell us to be careful at intersections and watch out for holes,” “personally, I take my own bag of sand with me and I prepare my intersection,” or “in my training group, we go over the CSST documents and that’s it.”

3.3.2 Risk factors identified through analysis of the focus groups

Using the factors cited by the focus group participants and the concepts defined in Section 2.1, our analysis of the discussions made it possible to itemize and categorize several risk factors involved in slip accidents. Three big groups of risk factors are listed in Table 18. They pertain to (1) the physical work environment, (2) the social work environment, and (3) how the work is organized.

Regarding the physical work environment, the main risk factors identified concern the nature of the underfoot surface, the lack of supports (handrails in stairways, railings), obstructions on roadways, and the lack of clearly visible demarcations. These are compounded by weather conditions, the general conditions of the work premises or location, and the wearing of inadequate footwear (for example, wearing boots unsuitable for the work season, such as using summer boots in winter and vice versa). In fact, the underfoot surface may be slippery due to ice, debris, or rubble, but can lead to a risk of accidents due to a change in level, as in the case of holes or sidewalks. The absence of handrails when going up or down stairways was also cited as a cause of these slip accidents. Obstructions created by objects (such as rocks) or demarcations (gratings, fences, hedges) that are not visible also contribute to accidents as indicated in the following testimonial: “a small fence can be buried under the snow and you don’t see it and that’s dangerous because that’s how a co-worker of mine fell.” Similarly, the risk of falling inside a premise (home, police station) was also described by the people interviewed, particularly at times when the floor might be slippery (for example, during housekeeping), when stairs are present (changes in level), or when there are no handrails to hold onto. Clutter caused by cardboard boxes or other materials that hinder walking was also cited.

Table 18 Identification of secondary extrinsic risk factors in slip accidents during meetings with the focus groups

Physical environment	Social environment	How the work is organized

• Weather conditions
• Condition of the premises
• Inadequate lighting
• Nature of the ground (outside):
  o Slippery surface (ice, snow accumulation)
  o Debris, rubble
  o Damaged (holes)
  o Type (concrete, tar, smooth surface)
  o Presence of changes in level (stairway, sidewalk)
• Nature of the floor (inside):
  o Slippery floor during daily maintenance
  o Type (tiles)
• Presence of changes in level (stairway)
• No supports (handrails)
• Obstructions created by objects, etc.
• Demarcations not visible (gratings, fences, hedges)
• Equipment:
  o Inadequate footwear (size, comfort)
	• Relationship to others and courtesy:
	  o Failure to obey the laws (fleeing, refusing to comply)
	  o Failure to obey the *Highway Safety Code* (not stopping at stop signs)
	  o Failure to obey the instructions given by the school crossing guard
		• Distribution of tasks and resources
		• Procedures for maintaining roads:
		  o Parking lots, streets near police stations and intersections monitored by school crossing guards
		  o Snow removal, spreading of abrasives
		• Procedures for maintaining work premises or location:
		  o Lack of lighting (police stations and intersections)
		• Policies for purchasing equipment (footwear/boots):
		  o Choice of footwear
		  o Orders (point systems)
		  o Wait times
		• Training:
		  o Choice of adequate equipment (footwear, anti-slip features)
		  o Risk of slipping, tripping, and losing balance

The social environment concerns relationships with others and rules of civility in general. Failure to obey orders or laws (fleeing, refusing to comply) and safety rules (stopping at stop signs, not waiting for the order to cross from the school crossing guard, police officer, or highway controller) are also probable accident causes often cited by these workers: "I had to catch a little kid who wanted to take off quickly and I fell near the sidewalk," "I didn't put on my cleats and that's why I fell, for sure," "he drove by fast, so I had to stop everybody and I did that too quickly, so I fell at the intersection," "I stopped someone after the intersection; he was driving fast, and when I was leaving I didn't see the ice and that's when I fell."

Certain aspects of the way in which the work is organized can influence the presence or not of certain risk factors. For example, the risk of slip accidents is that much greater when the underfoot surface on which the workers are walking is poorly maintained. The testimonials given by the school crossing guards supported this, particularly in the case of snow-covered sidewalks: "the city didn't have time to do everything and we ended up having to clear the crosswalks ourselves so people could cross." Road maintenance was also mentioned: "I didn't see the hole between two slabs of pavement and I fell because the snow hadn't been removed from that area."

As for the police officers, the maintenance of walkways and parking lots around police stations was also mentioned frequently. For example, "the owner didn't remove the snow from the parking lot, so I fell because there was a big patch of ice and snow." And even more often, some police officers and highway controllers reported that maintenance is not done on a daily basis: "I fell because no salt had been spread at the entrance to the office." The lighting on some streets and walkways is also insufficient to guarantee good visibility for police officers and school crossing guards, sometimes leading to slip accidents due to poorly lit premises: "It was the end of my shift, I left through the main entrance, it was pitch black outside, and I didn't even see that the whole road was icy."

3.4 Footwear

As the literature review revealed, low friction between the footwear and the underfoot surface is considered the main risk factor for slips. Moreover, the recommendations issued following accidents usually concern the installation of anti-slip flooring or the use of anti-slip footwear. In this exploratory study, particular attention was paid to footwear and work boots during the meetings with the focus groups. The discussions revealed the importance that the police officers, highway controllers, and school crossing guards place on the boots they wear and the differences between the groups with regard to equipment purchasing. These differences concerned both the way in which the workers obtain their boots and footwear and the absence of a choice of models. According to the police officers interviewed, only the central store is authorized to supply boots and it does so according to a point system. Yet a number of organizational constraints prevent the workers from choosing the model they need or obtaining the right size footwear:

- "We don't have access to other stores; it's the central store that gives us our boots."
- "Boots aren't considered safety equipment."
- "There are better adapted boots but we never get them."
- "The suppliers change from year to year and sometimes the sizes of the same boot change."
- "There are no half-sizes, and when you're a woman with small feet, you've really got a problem."
- "It takes too long to get your boots."
- "We aren't shown any other models of boots."
- "We don't have enough choice if we compare ourselves to ambulance technicians," and "the people who make the choices are civilians and they don't know the realities we face."
- "At the end of the day, you choose the least expensive (...); they don't ask our opinion and we don't try them on."
- "We never test them out in the field; why can't we have several types of boots to try out for a whole season?"
- "The boots aren't adapted to very cold weather, and when you're waiting at an intersection for the traffic to go by, you can no longer feel your feet after a few minutes."
- "Members of SWAT teams go to stores (...) they choose what they want."

According to the school crossing guards interviewed, their boot purchasing system does not depend on a central store. Instead, they buy their own boots and are reimbursed a fixed amount. They are also provided with cleats or anti-slip sole attachments free of charge. By contrast, wearing cleated soles is not generally authorized for the police officers, mainly due to the driving risks these soles pose.

The boot brands (see Figure 8) most frequently used by the police officers are as follows: Bates, Magnum Interceptor, and Royer. The highway controllers are required to wear CSA-certified boots. According to the focus group participants, these boots have not been tested by workers to show their suitability or not for their tasks.

In addition, although the soles of these boots have specific characteristics (Vibram MDT outsole, Oil & slip-resistant, W-154 (Rubber outsole), ISO 20347, Individual comfort System Technology), no scientific study was found that identified which soles offered the best anti-slip properties. While some footwear manufacturers submit the anti-slip properties of their products to specialized laboratories for evaluation, either the results are rarely available or the tests performed are inappropriate for icy/snowy conditions.

Bates boots	Magnum Interceptor boots	Royer boots	Example of a CSA-certified boot
			

Figure 8 Models of boots used by the police officers and highway controllers participating in the focus groups

Lastly, when asked the question “What would be the best boot for your work?”, the police officers, school crossing guards, and highway controllers gave a number of answers. Table 19 presents a summary of these answers. Most often they concerned the lightness of the boot, whether it was warm enough, and the choice of sizes.

Table 19 Description of the boot characteristics the participants wanted

Group	Current situation	Boot characteristics wanted
School crossing guards	• Choice of boots available, but “depends on the price” • Anti-slip sole attachments “don’t really work”	• Gore-Tex • Light • Must provide ankle support • Warm • Choice of sizes • Removable cleats, “don’t make everything possible, but could help”
Police officers	• No choice of boots or sizes • No choice of Gore-Tex boots (in some cases)	
Highway controllers	• No Gore-Tex boots because of CSA-certification requirement • No choice of boots or sizes	

The importance that the workers place on their work boots/footwear, which was evidenced in the focus groups, is not reflected proportionally in the statistical analysis of the accidents/incidents that occurred during the 2007–2009 period. The boots or footwear worn were specifically mentioned in only two events (3.5%) involving the school crossing guards (see Table 34, Appendix C). The victims of these two events considered that wearing cleats did not appear to have helped them avoid the accident/incident. The boots or footwear worn were mentioned in 26 events (5%) involving the police officers (see Table 34, Appendix C). A few of these events made reference only to the model of boots worn by the worker during the event (7 cases). In other events, it was the worker who slipped on a surface that became wet because of his wet or snowy boots or overshoes (12 cases). In seven cases, the boots/footwear worn may have contributed to the accident/incident. In other words, the fact of wearing inadequate boots/footwear does not appear to have been an explicit or frequent cause. However, given the many events caused by low friction between the footwear and the underfoot surface (particularly icy/snowy ground), the choice of more adequate footwear clearly remains an issue.

The literature review, discussed in Section 3.1.3, showed that the risks of slips and falls are in fact partly related to footwear properties (materials, geometry, hardness and roughness of the sole). The review further underscored the fact that the risks are also related to the condition of the underfoot surface (geometry and properties of the surface, ground/floor contamination), to the normal load, and to the slip velocity at heel contact (Gao and Abeysekera, 2004a). A number of studies reported on the effect of soling characteristics on use in a winter climate, which constitutes the main environmental risk factor for the police officers and school crossing guards. As summarized in Table 20, the materials used in soling manufacture, their tread design, and their hardness and roughness have effects on the coefficient of friction (adhesion or grip) between the sole and the underfoot surface. However, the effects can be different and sometimes even opposite, depending on the temperature and condition of the ice. Ice can actually be very slippery at a temperature near 0 °C and a fast gait speed, and much less slippery at a lower temperature (–40 °C) and slower gait speed. In general, the ice characteristics seem to be a more significant determinant of the friction during a slip than the viscoelastic properties of the soling materials (Roberts, 1981). Also, as sole topography can be greatly altered with wear, the anti-slip properties of footwear can deteriorate over time (Kim, 2004). It can therefore be difficult at times to identify an ideal sole because it may be suitable in specific winter conditions when new, but not appropriate after wear or in other winter conditions. This is all the truer in regions where the winter weather is very variable, changing from rain, to ice at 0 °C, to ice at –10 °C, sometimes within the same day.

For the aforementioned reasons, while footwear soles have an important role to play in preventing slips, they must not be regarded as the only solution. As we have little control over the nature of the ground or the weather, snow removal and spreading abrasives remain the preferred solutions wherever possible. It is conceivable that the gain in friction may be bigger with an anti-slip underfoot surface than with anti-slip footwear, as has been shown for floors (Leclercq, 1997b) and for certain types of icy ground (Roberts, 1981).

Table 20 Summary of the effect of soling characteristics on icy and snowy ground, based on the scientific literature consulted (see Section 3.1.3 of this report)

Soling characteristic	Effect on the coefficient of friction (COF)

Material	• Generally speaking, the COF of footwear is lower on icy surfaces than on other substrates.
	• Soft, thermoplastic rubber-based materials (nitrile rubber or natural rubber) are generally recommended for use on dry ice at –10 °C (Grönqvist and Hirvonen, 1995; Abeysekera and Gao, 2001).
	  • Nitrile rubber materials, double-density PU, thermoplastic PU, styrene rubber, rubber and glass fiber mixture, crepe rubber, and microcellular PU (Gao et al. 2003) have
	    o a low COF on melting ice (0 °C);
	    o a higher COF on hard ice at –10 °C than on a lubricated steel plate.
	• Crepe rubber (such as that on curling shoes) is recommended for the soles of footwear intended for use on hard ice at –10 °C (Gao et al., 2003).

Tread	• The studies documented essentially focus on slip resistance on wet or glycerol-contaminated floors. • On hard ice (–10 °C), flat cleats provide higher friction values (Grönqvist and Hirvonen, 1995). • On melting ice (0 °C), sharp cleats provide higher friction values (Grönqvist and Hirvonen, 1995).
Hardness	• The harder the sole, the lower the COF on dry ice at–10 °C (Bruce et al., 1986; Grönqvist and Hirvonen, 1995).
Roughness (asperity)	• The studies documented essentially focus on slip resistance on surfaces other than ice and snow. • Generally speaking, the rougher the sole, the higher the dynamic friction (Gao et al., 2004). However, on other surfaces, the COF diminishes with soles that have asperities, but increases with smooth soles (Tisserand, 1985).

4. DISCUSSION AND CONCLUSION

The aim of this exploratory research activity was to document the problem of slip accidents by identifying various risk factors associated with this type of accident. Three steps were carried out to achieve this aim. Each step shed light on different aspects of the problem.

The literature review made it possible to identify the concepts underlying the various risk factors involved in slip accidents. It detailed the main risk factor, which is friction between the footwear and the underfoot surface. As slip accidents are multifactorial in nature, the literature review also identified and described the role of secondary risk factors in slips. These may be extrinsic (environmental or organizational) or intrinsic (physiological or behavioural). What emerges from the literature review is the importance of the extrinsic environmental factors. These include the fact that the underfoot surfaces and the soles of the footwear worn are directly related to slip accidents. The literature review also brought to light the intrinsic factors and the mechanics of human locomotion. It appears that postural control strategies are needed to prevent slips. Among other things, the muscles of the lower extremities play a crucial role in maintaining and recovering balance. Scientific studies have shown that the critical phase in balance while walking is heel strike. A slight slip of the heel, which occurs naturally with nearly every step without the walker being aware of it, was correlated with slips of which the walker is aware. When a risk of slipping is perceived, the biomechanics of the gait change and are subject to the walker's perceptions of his environment. Lastly, slip accidents are correlated with poor physical condition and lack of experience.

Our statistical analysis of the accidents/incidents revealed that slips were involved in 55% of the STF events that occurred among the police officers and in 45% of the events involving the school crossing guards, which concurs with the data in the literature (Courtney et al., 2001). Analysis of the slip events allowed us to qualify the relative importance of various risk factors for the two study populations. Slip accidents, which occurred in 1.0% of the police officers and 1.0% of the school crossing guards annually, were more frequent among the women than the men. Accidents involving loss of work time involved an average absence duration of 61.6 days among the police officers and 110.3 days among the school crossing guards. Slip events were more frequent in the winter months. Icy/snowy ground was the preponderant risk factor for both groups. For the police officers, stairways also represented a risk factor for slides, sometimes combined with an icy/snowy surface or a surface that was wet because of boots. While police interventions (mainly calls) were the activity most often being carried out at the moment of the slip event, it also appears from our analysis that approximately one-third of the accidents/incidents occurred in the parking lot or vicinity of the police station, often on icy/snowy ground when the person was arriving at or leaving work. Running, a lack of visual cues, and carrying objects were additional risk factors. The main risk factor for the school crossing guards was icy/snowy ground on school crosswalks.

The focus groups made it possible to delineate the slip problem from the standpoint of workers in the target groups. These discussions confirmed the role played by the risk factors identified, including environmental factors such as the nature and condition of the underfoot surface, as well as the footwear and work boots. However, the brightest light cast by the focus groups concerned the work organization aspect of the problem. In fact, specific tasks such as interacting with others were important factors. In addition, the policies and procedures regarding equipment purchase and premise maintenance (snow removal, spreading of abrasives) can also influence the physical work environment and ultimately, worker safety.

Lastly, the three steps carried out made it possible to explore the relationships between footwear and slip accidents. The literature review provided the theoretical and scientific foundations for the interaction between footwear and the underfoot surface, while the focus groups highlighted the importance the workers place on the boots and footwear they are required to wear for their work.

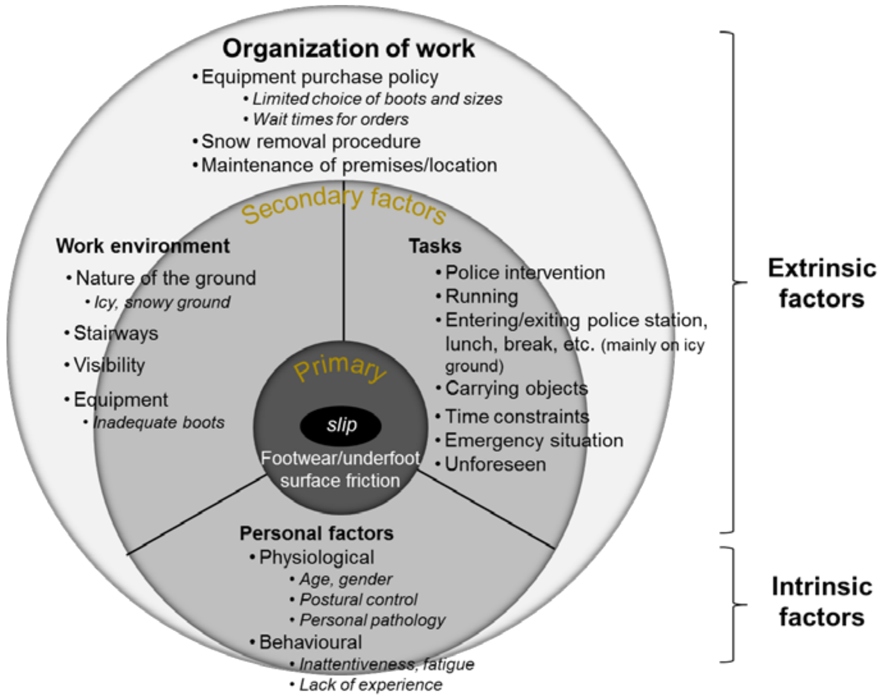
4.1 The proposed model

The results presented confirm the complexity and diversity of the risk factors involved in slip accidents. In this section, a model is proposed for each target group to illustrate the main determinants and how they interact. The model (for police officers in Figure 9a and for school crossing guards in Figure 9b) shows how the various risk factors interrelate in terms of their level of influence on slips.

The model represents slips (or safety with respect to slips) as the result of interactions among the various risk factors. In other words, slips occur due to the presence of one or more risk factors. The friction at the interface of the footwear/underfoot surface is automatically associated with slip accidents as it is the primary risk factor. Next, three categories of risk factors are directly involved in slips. They constitute the secondary risk factors and form the first “layer” of risk factors that have an impact on slips and that characterize the friction at the footwear/underfoot surface interface. These secondary factors may be intrinsic (1st category) and physiological or behavioural in nature, or extrinsic and related to the physical work environment (2nd category) or associated with the work tasks or activities (3rd category). Then come all the factors related to how the work is organized. In this respect, the overall organization of the work influences the presence or significance of the secondary risk factors. It forms the last layer of factors having an impact on slip accidents.

Maintenance of the work premises/location is an important aspect of the organization of work that was raised by the participants. Police officers depend on municipal departments, companies, and individuals that maintain the public or private areas where they have to work. This is one of the reasons why the police officers rely so heavily on their work boots or footwear to protect themselves. However, the risk of slips on walkways and in parking lots near police stations is significant, even if the officers walking there are not involved in an actual intervention. However, the maintenance of these areas is not always the police station’s responsibility, particularly in cities. In fact, in cities, the officers may have to park on the street or in a parking lot that is leased by the police department but maintained by the lot owner. Regarding school crossing guards, intersections and school crosswalks do not appear to undergo systematic maintenance. In some zones, the school crossing guards have abrasive made available to them that they can spread themselves before starting their work.

a) Model for police officers



b) Model for school crossing guards

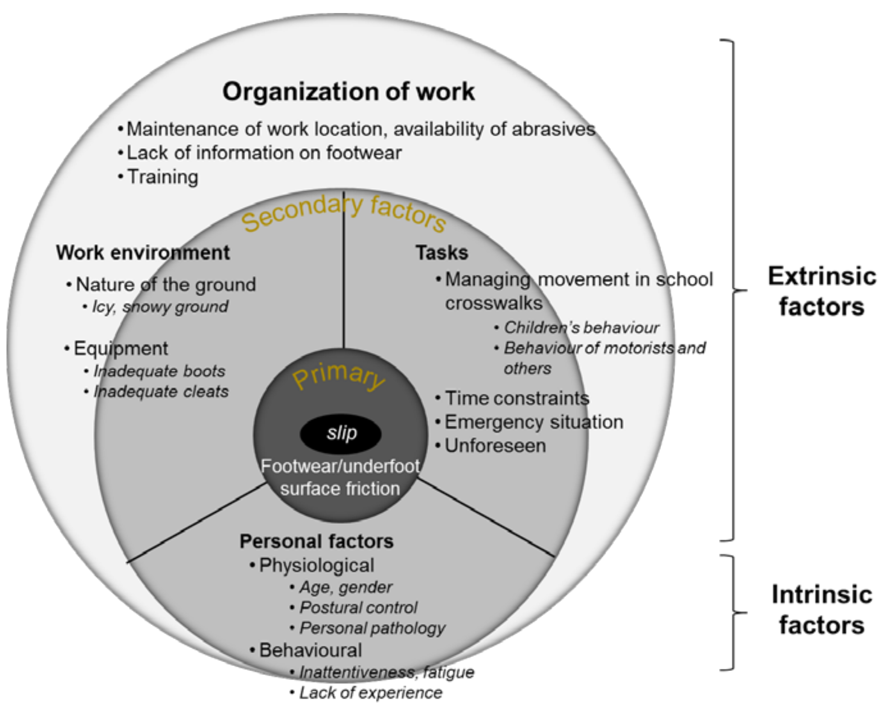


Figure 9 Models proposed to illustrate all risk factors involved in slip accidents

Another important aspect of how work is organized for police officers involves the equipment purchase policies. The workers claim that the choices underlying these purchasing policies and procedures do not seem adequately justified.

With relevant modifications, the model proposed here for slip accidents could prove useful as a means of representing the overall STF problem. This model would then be accident-centred, without making specific reference to footwear/underfoot surface friction, and the risk factors would characterize all STF events.

4.2 Scope and limitations of the study

The collection of data from different sources of information made it possible to document and confirm some of the risk factors involved in slip accidents and to delineate the issues associated with such accidents/incidents in the target work organizations. The occupational safety issues that emerged from this exploratory study concern mainly winter weather and outdoor surfaces (icy ground, sloping terrain), stairways, tasks or activities requiring interaction with others, maintenance of the work premises/location (snow removal and spreading of abrasives), and the purchase of boots or footwear adapted to work performed in winter conditions. These issues were identified for the police officers and school crossing guards in the organizations studied, but may also apply to other types of jobs where work is performed outdoors in winter conditions, such as delivery workers or postmen. The literature review provided an overall picture of the knowledge of slip accidents acquired by the scientific community, particularly regarding footwear/underfoot surface interaction and the mechanics of human movement on slippery surfaces. The results presented in this report help to identify research priorities in order to meet work organization needs and to target appropriate preventive interventions.

While this exploratory study led to a proposed model providing an overview of the underlying factors in slip accidents for police officers and school crossing guards, it has some limitations. Among other things, the decision to restrict the study to slip accidents meant that the scientific knowledge review could not be broadened to include the entire STF problem and other balance perturbations that are nonetheless present among both police officers and school crossing guards, judging from the statistical analysis of these events presented in Appendix B. While the results of that analysis show tendencies similar to those for slip accidents, certain risk factors (such as the ‘uneven terrain/hole/sidewalk/change in level’ factor) appear to play a bigger role. Also, a review of the literature on all STF accidents would have shed light on the various loss-of-balance mechanisms that enter into play, depending on whether the event involves slipping, tripping, pushing/pulling, or being struck by someone or something.

The scope of the statistical analysis of the slip accidents/incidents was limited, partly due to the small number of events in the two groups studied (particularly the school crossing guards), and partly due to the content of the event descriptions. Generally speaking the descriptions gave few details on the event, and when they did, the details had more to do with what happened after the slip, i.e. what caused the injury, in order to substantiate the claim file. However, and as Courtney et al. (2001) also reported, the understanding of the accident causes might have been improved if the descriptions had included more details on the environmental conditions (visual conditions, type of indoor or outdoor environment), the characteristics of the footwear worn (footwear model, wear on the sole), the movements made by the worker immediately before the accident (running, walking, backing up, carrying, pushing/pulling, going up or down a stairway), the worker's familiarity with the underfoot surface conditions and the work situation, and his state of mind at the time (emergency situation, distraction, fatigue).

Lastly, it was impossible in this study to explore the full complexity of how work is organized in greater detail. Had this been possible, we would have been able to identify the current criteria for choosing footwear and boots, as well as the policies in place for spreading abrasives at school crosswalks. Nor was it possible in this study to explore the role of the intrinsic factors for the target populations, particularly whether or not the workers have acquired strategies to avoid slipping or falling, or whether the workers' experience and level of concentration or attention has an impact on the occurrence of slip accidents.

5. RECOMMENDATIONS

This exploratory study delineates the problem of slip accidents and identifies the various risk factors involved for the police officers and school crossing guards studied. The literature review, the analysis of the accident/incident files for a three-year period, and the holding of focus groups led to a proposed model that provides an overview of the risk factors associated with slip accidents. The model shows the many factors involved, their interaction, and their level of impact on slips. This integrated approach to the slip accident problem could help in the more effective targeting of possible preventive interventions. The results presented in this report open the doorway to a number of recommendations for work organizations and for continuing research work, as well as new research avenues that could address the concerns of work organizations.

5.1 Recommendations pertaining to work organizations

Based on the results of this study, a number of strategies for minimizing slip accidents can be recommended:

- Apply, inasmuch as possible, the basic recommendations
    - concerning maintenance of the work premises/location:
        - keep walkways, stairways, and parking lots clear (remove snow, clean up any spills or debris);
        - spread abrasives on roads, parking lots, walkways, and school crosswalks;
        - install handrails in stairways and any other appropriate areas;
    - concerning the use of adequate footwear:
        - soles adapted to the work situation, for example, on dry ice at –10 °C, flexible materials, possible use of flat cleats, rough surface;
        - footwear or boots that are not too heavy or cumbersome and that are the right size;
    - that promote safe performance of work activities:
        - provide sufficient lighting to allow for good visibility;
        - keep an eye out for risks so as to be able to adapt your gait and ensure greater locomotor stability;
        - acquire the necessary experience to know how to adjust your gait on a slippery surface;
        - improve your postural balance by keeping your body's centre of gravity within the base of support, wear less heavy and cumbersome footwear, and avoid carrying equipment that is too big.

- In collaboration with the joint sector-based associations, participate in updating fact sheets on slip accidents, with particular emphasis on work performed outdoors under winter conditions.

5.2 General recommendations pertaining to future research

This study's scope and limitations suggest a number of points that, if explored, would provide a more accurate understanding of the problem of both slip accidents and STFs as a whole, and make it possible to take the complexity of these accidents more effectively into account in preventive interventions.

- While slip accidents represent approximately half of all STF accidents/incidents, further work is needed on the overall STF problem, whether in the form of a literature review that would, among other things, identify the different loss-of-balance mechanisms, or of a more detailed analysis of all events or focus groups centred more on all types of situations related to STFs.
- To facilitate the identification of risk factors through event analysis, the event descriptions should provide more details on the environmental conditions (visual conditions, type of indoor or outdoor environment), the characteristics of the footwear worn (type of footwear, wear on the sole), the movements made by the worker immediately prior to the accident (running, walking, backing up, carrying, pushing/pulling, carrying, going up or down a stairway), the worker's familiarity with the underfoot surface conditions and the work situation, and his state of mind at the time of the accident (emergency situation, distraction, fatigue).

5.3 Proposed avenues for future research on slip accidents

This study showed the predominance of slip accidents on outdoor surfaces among the target populations. Winter conditions and stairways are the main environmental risk factors. Yet the prior research documented in our literature review focused more on slips that occurred on slippery indoor surfaces (contaminated floors, for example). Little research has actually concentrated on the prevention of slip accidents on icy and snowy surfaces (Gao et al., 2004). This is mainly due to the wide range of winter surfaces (hard ice, melting ice, variables in snow grain size and compactness, etc.). Several avenues for future research can therefore be suggested to meet the needs of work organizations and address problems not yet resolved through earlier research. In addition, given the complex nature of slip accidents, only an integrated approach will allow optimal solutions to be found in terms of accident prevention. The proposed avenues for future research must therefore reflect this approach:

- More in-depth study of the factors associated with accidents and with prevention and balance-recovery strategies:
    - Further research is needed to determine the degree of importance of the various factors and their combined impacts on slips followed by balance recovery and slips resulting in a fall, particularly on icy, snowy surfaces.

- Extrinsic factors related to how work is organized were raised in this study, particularly in the focus groups. Future studies on the factors associated with slip accidents should look more into this type of factor in order to trace back the possible causes of the accidents and thereby propose appropriate preventive strategies.
- Perception of risk, prevention training, slip training, and experience are also important. Participation in winter sports and gait balance training have both been suggested as measures that should be integrated into accident prevention initiatives (Gao and Abeysekera 2004b). Slip training has also yielded encouraging results with respect to capacity to recover balance and reduce the risk of slipping (Parijat and Lockhart, 2012; Rich, 2012). However, the impact for work organizations of all these types of training and the beneficial long-term effects on accident prevention all warrant further study.

- Study of the mechanisms of human locomotion on slippery outdoor surfaces (particularly icy and snowy surfaces) and in stairways, in order to develop postural control and slip prevention strategies:
  - Additional studies are needed to broaden our understanding of footwear/underfoot surface interactions during a slip. The data obtained could then be used to develop a more "biofidelic[12]" device for measuring slip resistance and friction under a variety of slippery conditions. We also believe that measuring slip resistance at the velocities, levels of force, pressures, and moments of contact observed during walking by means of such a device would considerably increase fall predictability. Better knowledge of foot kinetics during walking and slipping is therefore needed.
  - More in-depth study is also needed of postural control strategies in familiar and unfamiliar environments, as has been suggested by Redfern et al. (2001). For example, laboratory experiments could be conducted on different populations to improve understanding of compensatory gait responses during walking on icy surfaces and of fall and recovery mechanisms following a slip. This would in turn channel intervention-strategy development efforts toward human-centred interventions aimed at preventing slips and fall-related injuries.
  - The muscles of the lower extremities play an essential role in maintaining balance when walking and recovering balance after slipping. However, few studies have examined their contribution to these tasks or to the interactions between muscle activity and the other kinematic and kinetic parameters involved in slip prevention.
- Improved knowledge of the relationship between footwear characteristics and slips under icy and snowy conditions, in order to improve the anti-slip properties of footwear:
  - To date, very few test methods have been developed to measure the slipperiness of footwear on icy and snowy surfaces. More in-depth studies are also needed to identify and analyze specific criteria that determine footwear performance. The mechanisms of interaction between footwear and icy surfaces require further investigation, and test methods need to take better account of these specifics.

[12] "Biofidelic" can be defined as mimicking pertinent human physical characteristics or functions.

- As reported by Gao and Abeysekera (2004a) among others, little literature exists on the anti-slip properties (treads, hardness, roughness) of footwear soles intended for use on icy and snowy surfaces. While some of the principles established in studies on lubricated floors may apply, additional research is needed to isolate the impact of each property on friction at the sole/underfoot surface interface and to identify the different footwear requirements that suit the various work organizations.
- Given that weather conditions and sudden changes in temperature have an impact on the COF, studies need to be conducted on the impact of these parameters on the incidence of slip accidents in various environments and for different types of soling material.
- It has been shown that the tread of the soling on the heel has an impact on the slip resistance of footwear. However, as reported by Gao and Abeysekera (2004a), the role of the front part of the sole, which is involved during the backward slide and toe-off, has been the subject of little research. More in-depth studies are therefore needed to determine the role played by the type of sole on the front part of the footwear in preventing slips.

BIBLIOGRAPHY

Abeysekera, J., Gao, C., 2001. The identification of factors in the systematic evaluation of slip prevention on icy surfaces. International Journal of Industrial Ergonomics 28, 303–313.

Ahagon, A., Kobayashi, T., Misawa, M., 1988. Friction on ice. Rubber and Chemistry and Technology 61, 14–35.

Andreani, J.-C., Conchon, F., 2001. Méthodes d'analyse et d'interprétation des études qualitatives: État de l'art en marketing, Rapport No ESCP-EAP-01-150, INIST-CNRS, Cote INIST: DO 7385, 170 p.

APSAM, 2006. "Des semelles à crampons pour les brigadiers scolaires." http://www.apsam.com/publication/brigadiers/crampons.pdf. [Last accessed on August 19, 2014].

APSAM, 2007. Série de documents produits par l'APSAM et l'APSSAP en format électronique et ayant pour thème « Prévenons les chutes et les glissades - Gardons les pieds sur terre » : 1) La prévention passe par un plan d'action, 2) Les voies de circulation et la tenue des lieux, 3) Des chaussures appropriées aux types de surface, et 4) Avis de chute. Ces quatre fiches sont disponibles sur le lien http://www.apsam.com/site.asp?page=themes&nid=567. [Last accessed on August 19, 2014].

Aschan, C., Hirvonen, M., Rajamäki, E., Mannelin, T. 2004. Assessing slip resistance of wintery walkways with a novel portable slipmeter. Walk21-V Cities for People, The Fifth International Conference on Walking in the 21st Century, June 9-11 2004, Copenhagen, Denmark.

Bentley, T.A., Haslam, R.A., 1998. Slip, trip and fall accidents during the delivery of mail. Ergonomics 41(12), 1859–1872.

Bingham, A., Rose, S. 2011. New slip resistance method – SATRA TM144:2011. Recent developments to improve and update the slip resistance test method. SATRA Bulletin. http://www.satra.co.uk/bulletin/article_view.php?id=658. [Last accessed on August 19, 2014].

Bloswick, D.S., Love, A.C., 1991. Slip potential during load carrying activities. Slip, Trip, Fall. University of Surrey, Guildford, United Kingdom.

Bruce, M., Jones, C., Manning, D.P., 1986. Slip resistance on icy surfaces of shoes, crampons and chains—A new machine. Journal of Occupational Accidents 7, 273–283.

Cham, R., Redfern, M.S., 2001. Lower extremity corrective reactions to slip events. Journal of Biomechanics 34(11), 1439–1445.

Cham, R., Redfern, M.S., 2002a. Heel contact dynamics during slip events on level and inclined surfaces. Safety Science 40, 559–576.

Cham, R., Redfern, M.S., 2002b. Changes in gait when anticipating slippery floors. Gait and Posture 15, 159–171.

Chang, W., Grönqvist, R., Leclercq, S., Myung, R., Makkonen, L., Strandberg, L., Brungraber, R., Mattke, U., Thorpe, S., 2001a. The role of friction in the measurement of slipperiness, Part 1: Friction mechanism and definition of test conditions. Ergonomics 44, 1217–1232.

Chang, W.R., Grönqvist, R., Leclercq, S., Brungraber, R.J., Mattke, U., Strandberg, L., Thorpe, S.C., Myung, R., Makkonen, L., Courtney, T.K. 2001b. The role of friction in the measurement of slipperiness, Part 2: Survey of friction measurement devices, Ergonomics, 44, 1233 – 1261.

Chang, W., Chang, C., Matz, S., Son, D.H., 2004. Friction requirements for different climbing conditions in straight ladder ascending. Safety Science 42, 791–805.

Cooper, R. C., Prebeau-Menezes, L.M., 2008. Step length and required friction in walking. Gait & Posture 27, 547–551.

Courtney, T.K., Sorock, G.S., Manning, D.P., Collins, J.W., Holbein-Jenny, M.A., 2001. Occupational slip, trip, and fall-related injuries—can the contribution of slipperiness be isolated? Ergonomics 44 (13), 1118–1137.

CSA Z195-09. 2009. Protective Footwear, Canadian Standards Association, Mississauga (Ontario), Canada.

De Koning, J. J., De Groot, G., Schenau, J.V.I., 1992, Ice friction during speed skating, Journal of Biomechanics, 25, 565–571.

Denbeigh, K. 2013. Slips During Gait on Winter Surfaces: Evaluation of Ice Cleat Design and Slip Definition, Master Thesis, Institute of Biomaterials and Biomedical Engineering, University of Toronto.

English, W., 1994. The validation of slipmeters, in S.A. Robertson (ed.), Contemporary Ergonomics 1994, (London: Taylor & Francis), 347–352.

Fothergill, J., O'Driscoll, D., Hashemi, K., 1995. The role of environmental factors in causing injury through falls in public places. Ergonomics 38, 220–223.

Gao, C., Abeysekera, J., 2002. The assessment of the integration of slip resistance, thermal insulation and wearability of footwear on icy surfaces. Safety Science 40, 613–624.

Gao, C., Abeysekera, J., Hirvonen, M., Aschan, C., 2003. The effect of footwear sole abrasion on the coefficient of friction on melting and hard ice. International Journal of Industrial Ergonomics 31, 323–330.

Gao, C., Abeysekera, J., Hirvonen, M., Grönqvist, R., 2004. Slip resistant properties of footwear on ice. Ergonomics 47 (6), 710–716.

Gao, C., Abeysekera, J., 2004a. A system perspective of slip and fall accidents on icy and snowy surfaces. Ergonomics 47 (5), 573–598.

Gao, C., Abeysekera, J., 2004b. Slip and falls on ice and snow in relation to experience in winter climate and winter sport. Safety Science 42, 537–545.

Gauchard, G., Chau, N., Mur, J.M., Perrin, P., 2001. Falls and working individuals: role of extrinsic and intrinsic factors. Ergonomics 44(14), 1330–1339.

Grieve, D.W., 1983. Slipping due to manual exertion. Ergonomics 26(1), 61–72.

Grönqvist, R., Hirvonen, M., Tuusa, A., 1993. Slipperiness of the shoe-floor interface: comparison of objective and subjective assessments. Applied Ergonomics 24, 258–262.

Grönqvist, R., Hirvonen, M., 1995. Slipperiness of footwear and mechanisms of walking friction on icy surfaces. International Journal of Industrial Ergonomics 16, 191–200.

Grönqvist, R., Chang, W., Courtney, T.K., Leamon, T.B., Redfern, M.S., Strandberg, L., 2001a. Measurement of slipperiness: fundamental concepts and definitions. Ergonomics 44(13), 1102–1117.

Grönqvist, R., Abeysekera, J., Gard, G., Hsiang, S.M., Leamon, T.B., Newman, D.J., Gielo-Perczak, K., Lockhart, T.E., Pia, Y.-C., 2001b. Human-centred approaches in slipperiness measurement. Ergonomics 44, 1167–1199.

Hanson, J.P., Redfern, M.S., Mazumdar, M., 1999. Predicting slips and falls considering required and available friction. Ergonomics 42, 1619–1633.

Horak, F.B., Henry, S.M., Shumway-Cook, A., 1997. Postural perturbations: new insights for treatment of balance disorders. Physical Therapy 77, 517–33.

Jung, K., 1992. Factors influencing anti-slip properties of footwear, Proceedings of The Fourth Scandinavian Symposium on Protective Clothing Against Chemicals and Other Health Hazards, (Helsinki: NOKOBETEF), pp. 112–122.

Kim, I.-J., 2004. Development of a new analyzing model for quantifying pedestrian slip resistance characteristics: Part I–Basic concepts and theories. International Journal of Industrial Ergonomics 33, 395–401.

Kong, P.W., Suyama and Hostler, 2013. A review of risk factors of accidental slips, trips, and falls among firefighters. Safety Science 60, 203-209.

Krippendorff, K., 2003. Content analysis: an introduction to its methodology. 2nd edition, Sage Publications, Thousand Oaks, CA.

Leamon, T.B., Li, K.W., 1990. Microslip length and the perception of slipping, paper presented at the 23rd International Congress on Occupational Health, Montreal, Canada.

Leamon, T.B., Murphy, P.L., 1995. Occupational slips and falls: more than a trivial problem. Ergonomics 38, 487–498.

Leclercq, S., 1997a. La prévention des chutes de plain-pied. Bilan. Perspectives, dans Les notes scientifiques et techniques de l'INRS, (Paris: INRS), juillet, n° 157, NS 0157, 57 p.

Leclercq, S., 1997b. Prévention des chutes de plain-pied. Synthèse des travaux et recommandations, dans Les cahiers de notes documentaires – Hygiène et sécurité du travail de l'INRS, (Paris: INRS), n° 169, 4e trimestre, 621-633.

Leclercq, S., 1999. The prevention of slipping accidents: a review and discussion of work related to the methodology of measuring slip resistance. Safety Science 31, 95–125.

Leclercq, S. 2003. La sécurité vis-à-vis des glissades : Facteurs déterminant la résistance au glissement des sols. Cahiers de notes documentaires – Hygiène et sécurité du travail, No 190, 1er trimestre, p.25-31.

Leclercq, S., Tissot, C. 2004. Les chutes de plain-pied en situation professionnelle. Circonstances de chutes particulièrement graves à travers l'analyse statistique de 459 cas, dans Les cahiers de notes documentaires – Hygiène et sécurité du travail de l'INRS, (Paris: INRS), n° ND 2206-194-04, 1e trimestre, 51-66.

Leclercq, S., Monteau, M., Cuny, X. 2010. Avancée dans la prévention des « chutes de plain-pied » au travail, Perspectives interdisciplinaires sur le travail et la santé, 12 (3), http://pistes.revues.org/2667. [Last accessed on August 19, 2014].

Leroux, A., Fung, J., Barbeau, H., 2002. Postural adaptation to walking on inclined surfaces: I. Normal strategies. Gait & Posture 15(1), 64–74.

Li, K.W., Chen, C.J., 2004. The effect of shoe soling tread groove width on the coefficient of friction with different sole materials, floors and contaminants. Applied Ergonomics 35, 499–507.

Li, K.W., Wu, H.H., Lin, Y.-C., 2006. The effect of shoe sole tread groove depth on the friction coefficient with different tread groove widths, floors and contaminants. Applied Ergonomics 37, 743–748.

Lin, L.J., Chiou, F.T., Cohen, H.H., 1995. Slip and fall accident prevention: a review of research, practice, and regulations. Journal of Safety Research 26, 203–212.

Liu, L., Li, K.W., Lee, Y.-H., Chen, C.C., Chen, C.-Y., 2010. Friction measurements on ''anti-slip" floors under shoe sole, contamination, and inclination conditions. Safety Science 48, 1321–1326.

Maki, B.E., McIlory, W.E., 1997. The role of limb movements in maintaining upright stance: the 'change-in-support' strategy. Physical Therapy 77, 488–507.

Manning, D. P., Ayers, I., Jones, C., Bruce, M., Cohen, K., 1988. The incidence of underfoot accidents during 1985 in a working population of 10,000 Merseyside people. Journal of Occupational Accidents 10, 121–130.

Manning, D.P., Jones, C., 2001. The effect of roughness, floor polish, water, oil and ice on underfoot friction: current safety footwear solings are less slip resistant than microcellular polyurethane. Applied Ergonomics 32, 185–196.

Marigold, D.S., Patla, A.E., 2002. Strategies for dynamic stability during locomotion on a slippery surface: effects of prior experience and knowledge. Journal of Neurophysiology 88, 339–353.

McIlroy, W.E., Maki, B.E., 1995. Adaptive changes to compensatory stepping responses. Gait & Posture 3, 43–50.

Myung, R., Smith, J.L., 1997. The effect of load carrying and floor contaminants on slip and fall parameters. Ergonomics 40, 235–246.

Nagata, H., 1991. Occupational accidents while walking on stairways. Safety Science 14, 199–211.

NF EN ISO 13287:2012. 2012. Personal Protective Equipment. Footwear. Test Method for Slip Resistance. European Committee for Standardization, Brussels, Belgium.

Parijat, P., Lockhart, T.E. 2012. Effects of moveable platform training in preventing slid-induced falls in older adults. Annals of Biomedical Engineering, 40(5), 1111-1121.

Perkins, P.J., 1978. Measurement of slip between the shoe and ground during walking, in C. Anderson and J. Senne (eds.), Walkway Surfaces: Measurement of Slip Resistance, ASTM STP 649 (Philadelphia: American Society for Testing and Materials), 71–87.

Prud'homme P., Duguay P., Boucher A., Busque M.-A., 2012. Les chutes et glissades : un problème important pour les travailleurs québécois? In *Innovation in occupational health and Safety research*: Annual conference of the Canadian Association for Research on Work and Health / CARWH/ACRST, (June 1-2, 2012: Vancouver, Canada).

Redfern, M.S., Bidanda, B., 1994. Slip resistance of the shoe-floor interface under biomechanically relevant conditions. Ergonomics 37(3), 511–524.

Redfern, M.S., DiPasquale, J., 1997. Biomechanics of descending ramps. Gait and Postures 6, 119–125.

Redfern, M.S., Hanson, J.P., Mazumdar, M., 1998. Comparing required and available friction during walking to prevent falls. In S. Kumar (ed.) Advances in Occupational Ergonomics and Safety, (Amsterdam: IOS Press), 92–96.

Redfern, M.S., Cham, R., Gielo-Perczak, K., Grönqvist, R., Hirvonen, M., Lanshammar, H., Marpet, M., Pai, C.Y.-C., Powers, C., 2001. Biomechanics of slips. Ergonomics 44, 1138–1166.

Rich, B.M. 2012. Integrating safety with science, technology and innovation at Los Alamos National Laboratory. Report LA-UR-12-20335, Los Alamos National Laboratory, 4 pages.

Roberts, A.D., 1981. Rubber-ice adhesion and friction. Journal of Adhesion 13, 77–86.

Rhoades, T.P., Miller, J.M., 1988. Measurement and Comparison of “Required” Versus “Available” Slip Resistance. Proceedings of the 21st Annual Conference of the Human Factors Association of Canada, pp. 137–140.

Stevenson, M.G., 1992. Proposed standard testing methods for slip resistance. Journal of Occupational Health and Safety 8, 497–503.

Strandberg, L., Lanshammar, H., 1981. The dynamics of slipping accidents. Journal of Occupational Accidents 3, 153–162.

Strandberg, L., 1983. On accident analysis and slip-resistance measurement. Ergonomics 26, 11–32.

Strandberg, L., 1985. The effect of conditions underfoot on falling and overexertion accidents. Ergonomics 28(1), 131–147.

Sun, J., Walters, M., Svensson, N., Lloyd, D., 1996. The influence of surface slope on human gait characteristics: a study of urban pedestrians walking on an inclined surface. Ergonomics 39, 677–692.

Tanaka, T., Takeda, H., Izumi, T., Ino, S., Ifukube, T., 1999. Effects on the location of the centre of gravity and the foot pressure contribution to standing balance associated with ageing. Ergonomics 42, 997–1010.

Tisserand, M., 1969. Critères d'adhérence des semelles de sécurité. Rapport d'étude INRS.

Tisserand, M., 1985. Progress in the prevention of falls caused by slipping. Ergonomics 28(7), 1027–1042.

Wilson, M.P. 1990. Development of SATRA slip test and tread pattern design guidelines, in B. E. Gray (ed.), Slips, Stumbles, and Falls: Pedestrian Footwear and Surfaces, ASTM STP 1103 (Philadelphia: ASTM), 113-123.

Winter D.A. 1991. The biomechanics and motor control of human gait: normal, elderly and pathological. University of Waterloo Press, Ontario.

Yoon, H-Y., Lockhart, T.E., 2006. Nonfatal occupational injuries associated with slips and falls in the United States. International Journal of Industrial Ergonomics 36, 83–92.

You, J.Y., Chou, Y.L., Lin, C.J., Su, F.C., 2001. Effect of slip on movement of body center of mass relative to base of support. Clinical Biomechanics 16, 167–173.

APPENDIX A: STEPS CARRIED OUT PRIOR TO STATISTICAL ANALYSIS

Estimation of the annual worker population

The annual number of police officers and school crossing guards used to calculate the frequency rate is based on the data available on the annual population of these workers in the organizations studied. These numbers constitute estimates only, since the available data (presented in Table 21) do not necessarily concern the years 2007–2009 or correspond exactly to the age groups used for the event distribution.

Table 21 Annual population of police officer and school crossing guard personnel in the organizations studied, distributed by gender and age

Distribution by		Police officers		
		PD 1	PD 2	PD 3*
		Year 2010	Year 2010	Average for the 2007–2009 period
Gender	Female	1,345	180	951
	Male	3,086	540	4,163
Age	18-34	1,394	259	2,198
	35-44	1,706	331	1,835
	45+	1,331	130	1,081
Total annual population		4,431	720	5,114

	School crossing guards	
	City 1	City 2
	Year 2010	Year 2009
Female	402	195
Male	266	86
18-59	336	135
60+	332	146
	668	281

* In this case, the distribution by age group is estimated because the age groups available in the data transmitted initially were 18-35 years, 36-45 years, and 46 years and over.

Preliminary sorting of the STF events

A total of 776 events involving the problem of STFs were reported by the police departments and cities under study. Of this number, 167 files were excluded:

- 37 files for which the event description was missing or imprecise (30 files for the police officers and 7 for the school crossing guards);
- 130 cases involving falls during altercations for police officers in PD 1 (36 cases), PD 2 (50 cases), and PD 3 (44 cases).

The STF events included slips, trips, and other losses of balance, followed or not by a fall. Some of these events were coded by the CSST as accidents *on the same level*. The analyzed files also included events that occurred in a stairway, when jumping over or crossing an obstacle, and when getting into or out of a stationary vehicle. These events were categorized by the CSST as accidents involving *a lower level*. Table 22 shows the overall types of accidents/incidents determined by our analysis (Section 2.2.2.2) as well as the CSST codes that may be considered equivalent.

Table 22 Types of accidents/incidents related to the 609 events included in the study and equivalent CSST codes

Case	Category	Overall types of accidents/incidents	
Events included in the analysis (609 cases)	Fall on the same level	• **Slipping/tripping with or without a fall** Falling on the same level, slipping, tripping Slipping, tripping, WITHOUT FALLING	
	Fall to a lower level and jumps	• **Falling in a STAIRWAY or on steps** • **Falling when JUMPING over or CROSSING …** Falling when JUMPING OVER … Falling when CROSSING … • **Falling when getting into/out of a stationary VEHICLE**	
Equivalent CSST codes (for information purposes only)	Fall on the same level, slip, trip,	• Falling on the same level, n.s.*	13000
		• Falling on a floor, in a hallway, or on another surface	13100
		• Falling onto or against objects	13200
		• Falling on the same level, n.o.c. **	13900
	Bodily reaction (… without falling)	• Slipping, tripping, losing balance, without falling, n.s.	21500
		• Slipping on an object without falling	21501
		• Tripping on an object without falling	21502
		• Stepping in a hole without falling	21503
	Fall to a lower level and jumps	• Falling from a stationary vehicle	11800
		• Jumping from a stationary vehicle	12300
		• Falling in a stairway or on steps	11100

* n.s. = not specified
** n.o.c. = not otherwise classified

APPENDIX B: DESCRIPTIVE STATISTICS FOR ALL THE STF EVENTS

This appendix presents an analysis of all the STF events that occurred among the police officers in the three participating police departments during the 2007–2009 period and among the school crossing guards in the two cities studied, for the 2007–2009 period for City 1 and the 2008–2010 period for City 2. These events therefore include slips (for which a specific analysis is presented in Section 3.2 of this report), as well as trips, missteps, and any other losses of balance related to this problem, as defined in Section 2.1.

B.1 Results for the police officers

B.1.1 Frequency and severity of the STFs, by gender, age, and date of event

The total number of STF accidents/incidents was compiled for all the police officers in the three participating organizations. The annual frequency of the events relative to the number of police officers on staff, as well as the severity of the accidents involving loss of work time that occurred in 2007–2009, are presented by gender in Table 23 and by age in Table 24.

Table 23 Frequency (a) and severity (b) of STF events among the police officers in the three departments studied, by gender, for the 2007–2009 period

a) Annual frequency of events with and without loss of work time

Gender	Average no. of workers/yr.	Average no. of STFs/yr.	%
F	2,476 (24%)	57.7 (32%)	**2.3**
M	7,789 (76%)	124.7 (68%)	**1.6**
TOTAL	10,265 (100%)	182.3 (100%)	**1.8**

b) Severity of accidents involving loss of work time that occurred during the three-year period

Gender	No. of accidents with loss of work time	Average absence duration [days]	Median absence duration [days]
F	64	62.0	17.5
M	154	58.5	17.5
TOTAL	**218**	**59.5**	**17.5**

Table 24 Frequency (a) and severity (b) of STF events among the police officers in the three departments studied, by age, for the 2007–2009 period

a) Annual frequency of events with and without loss of work time

Age	Average no. of workers/yr.	Average no. of STFs/yr.	%
18-34	3,851 (38%)	89.0 (49%)	**2.3**
35-44	3,872 (38%)	57.3 (32%)	**1.5**
45+	2,542 (25%)	35.3 (19%)	**1.4**
TOTAL	10,265 (100%)	181.7 (100%)	**1.8**

b) Severity of accidents involving loss of work time that occurred during the three-year period

Age	No. of accidents with loss of work time	Average absence duration [days]	Median absence duration [days]
18-34	84	43.5	15.0
35-44	81	73.0	14.0
45+	53	64.3	30.0
TOTAL	**218**	**59.5**	**17.5**

STF accidents/incidents occurred among approximately 1.7% of the police officers annually for the 2007–2009 period, according to the data collected. Accidents involving loss of work time represented nearly 40% of all the events (see Table 1). These accidents resulted in an average absence duration of 59.5 days and a median absence duration of 17.5 days.

STF events occurred more frequently among the women, with an occurrence rate of 2.3% compared to 1.6% among men. This result follows the same tendency as observed in the CSST data (Prud'homme et al., 2012). The severity of the accidents involving loss of work time was similar in the men and women.

The young police officers under 35 years of age in the three police departments analyzed appear to have been those most affected by the problem. In fact, even though this age group made up 38% of the police personnel, it represented 49% of the officers affected annually. However, the severity of the accidents involving loss of work time increased with age. The average absence duration rose from 43.5 days for the 18- to 34-year age group to 64.3 days for those ages 45 years and over. Similarly, the median absence duration went from 15 days for the 18- to 34-year age group to 30 days for those ages 45 years and over. An examination of the most serious cases did not reveal any particular reason that would explain the high value of this last result. However, the tendency observed here is similar to that observed in an analysis of the CSST data for STFs among all Quebec workers (Prud'homme et al., 2012).

Figure 10 shows the number of events that occurred during the 2007–2009 period among the police officers, by month of the year. Event frequency was higher for the winter months. In fact, 55% of the cases occurred during the months of December, January, February, and March. The same tendency was observed in all three police departments studied.

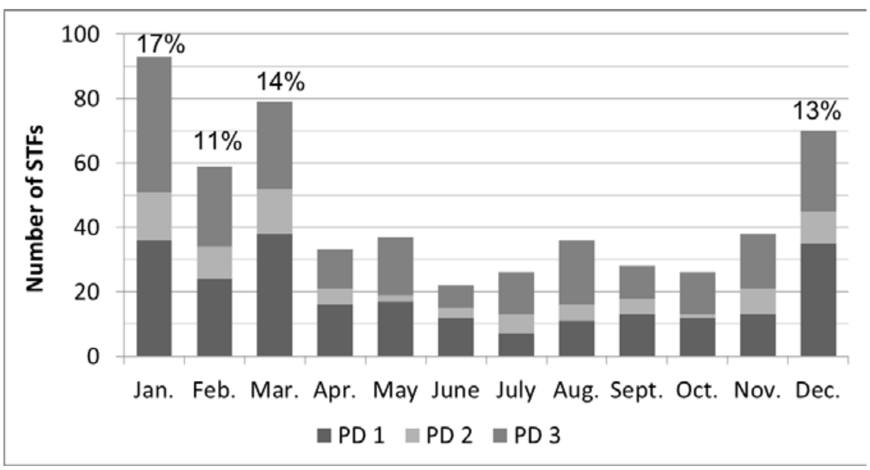


Figure 10 Distribution of the number of STFs that occurred among the police officers in the three police departments studied, by month of the year, during the 2007–2009 period

B.1.2 Distribution of the STFs by type of accident/incident

To obtain an overview of the incidence of the types of accidents/incidents that occurred during the 2007–2009 period for the three police departments, the number of events was compiled for the various levels of detail available for each type of accident/incident. Table 25 shows that slips, trips, and losses of balance with or without a fall represented (367/547) of all the cases. Falls in a stairway represented 21% of the cases, falls getting into/out of a vehicle 7%, and falls jumping over or crossing an obstacle (such as a fence or ditch) 5% of the cases. These results are similar to those obtained in a study conducted by the SPVM's joint committee[13], which found that falls in a stairway or near a vehicle and jumps over fences represented 27%, 7%, and 5% respectively of all cases in their study, for the 2002–2004 period.

Table 25 Distribution of the STFs, by *general* and *specific* types of accident/incident, among the police officers in the three departments studied during the 2007–2009 period

Type of accident/incident	**Slip, trip, loss of balance with/without fall**		**Fall in a STAIRWAY or on steps**	**Fall when getting into/ getting out of a stationary VEHICLE**	**Fall when JUMPING over or CROSSING …**		**Total**
	With fall	Without fall			When JUMPING over …	When CROSSING …	
Slipping on a surface	166	27	76	26	4	2	**301** ***55%***
Tripping	35	4	8		2	1	**50** ***9%***
Falling (not otherwise specified)	31		9	1	4	4	**49** ***9%***
Stepping into a hole	12	12	2	1		1	**28** ***5%***
Losing footing	13	1	9	2			**25** ***5%***
Twisting a foot		13	2	3	2		**20** ***4%***
Losing balance	12	1	2	2	1		**18** ***3%***
Being struck or pushed by ...	12	1					**13**
Stepping on something that gives way	3		4			2	**9**
Being dragged along by …	6				1		**7**
Taking an awkward step	1	3			2		**6**
Missing a step			5	1			**6**
Stepping into midair	5						**5**
Banging into ...	3				1		**4**
Falling into a hole	3						**3**
Being hit by a vehicle	2						**2**
Stepping on a nail		1					**1**
Total	**304** ***56%***	**63** ***12%***	**117** ***21%***	**36** ***7%***	**17** ***3%***	**10** ***2%***	**547** ***100%***
Aggregate TOTAL	**367** ***67%***		**117** ***21%***	**36** ***7%***	**27** ***5%***		**547** ***100%***

Table 25 also shows that over half of the events involved 'Slipping on a surface' (55%, 301/547 cases). The other most common *specific* types of accidents/incidents were 'Tripping' (9%), 'Falling (not otherwise specified)' (9%), 'Stepping into a hole' (5%), 'Losing footing' (5%), 'Twisting a foot' (4%), and 'Losing balance' (3%). Overall, the three organizations were affected by the same types of events. Although the results are not presented in this report, it is worth noting that with respect to 'Slips, trips, losses of balance with/without fall,' PD 1 seems to have had more cases without falls (23%) than the other two organizations (2% for PD 2 and 3% for PD 3). Also, PD 3 was the only one to have been affected by falls when crossing an obstacle, mainly due to the more frequent presence of ditches in the police officers' work environment.

[13] SPVM – Service de police de la Ville de Montréal, 2010. Joint-committee section (occupational health and safety). Personal communication [unofficial translation].

B.1.3 Distribution of the STFs by various extrinsic risk factors

B.1.3.1 Activities/tasks

Generally speaking, looking at all types of accidents/incidents combined (Table 26), most of the events (63%, 343/547 cases) occurred during **police interventions**. They usually involved responding to calls (patrol) (182 cases). The other types of interventions involved foot chases (8 cases), traffic assignments (21 cases), and responding to complaints (19 cases). The proportion of events occurring during police interventions (compared to those occurring during other types of activities) was higher in the cases of falls sustained when jumping over or crossing an obstacle (89%, 24/27).

Table 26 Distribution of the STFs, by type of activity/task for each type of accident/incident, for the police officers in the three departments studied during the 2007–2009 period

Type of accident/incident → / Type of activity/task ↓	Slip, trip, loss of balance with/without fall				Fall in a STAIRWAY or on steps				Fall when getting into/out of stationary VEHICLE			Fall when JUMPING over or CROSSING …			Aggregate TOTAL
	-	Running	Carrying objects	TOTAL	-	Running	Carrying objects	TOTAL	-	Carrying objects	TOTAL	-	Running	TOTAL	
Police intervention	**125**	**83**	**6**	**214**	**82**	**1**	**3**	**86**	**16**	**3**	**19**	**7**	**17**	**24**	**343**
Call/intervention	81	13	3	97	65		2	67	8	2	10	5	3	8	182
Foot chase		65		65		1		1					14	14	80
Traffic	18	1		19						1	1	1		1	21
Complaint	6	1		7	11		1	12							19
Accident	9	1		10	1			1	2		2	1		1	14
Police activity, n.o.s.*	8	1		9	3			3	1		1				13
Crime scene	2		1	3					4		4				7
Medical			2	2	2			2	1		1				5
Crowd control	1	1		2											2
Other	**129**	**2**	**11**	**142**	**13**		**2**	**15**	**16**	**1**	**17**	**3**		**3**	**177**
Entering/exiting patrol vehicle/police station	52		5	57	7		2	9	12		12				78
Training	40	1	1	42					1		1				43
Arriving at/leaving work	11		3	14					3	1	4				18
Other	8			8	2			2				1		1	11
Break/lunch/washroom/meeting	6			6	2			2				1		1	9
Physical fitness training	4		1	5	1			1				1		1	7
Removing snow/moving vehicle	6			6											6
Police event/conference/party	2	1	1	4	1			1							5
Activity not specified	**11**			**11**	**16**			**16**							**27**
Aggregate TOTAL	**265**	**85**	**17**	**367**	**111**	**1**	**5**	**117**	**32**	**4**	**36**	**10**	**17**	**27**	**547**

* n.o.s. = not otherwise specified

A significant proportion (32%) of the cases (177/547) also occurred during **other activities** seemingly requiring less attention or fewer interactions with the public (Table 26). For example, these might involve entering or leaving the police station or getting into/out of the patrol vehicle (78 cases), doing training (43 cases), or arriving at or leaving work (8 cases). The significant proportion of cases occurring during other activities was particularly noticeable in the 'Slip, trip, loss of balance with/without fall' (39%, 142/367) and 'Fall when getting into/out of a vehicle' (47%, 17/36) types of accidents/incidents. **Running** was a risk factor in 19% of the events (103/547) (Table 26). This factor played a role in 29% of the cases occurring during police interventions (101/343), most of them during a foot chase. Similar results were found in a study conducted by the SPVM's joint committee[14], in which 23% of the STFs occurred during running. The large number of cases that occurred during running was particularly noticeable in the 'Fall when jumping over or crossing an obstacle' type of accident/incident (with 63% of these events occurring during running, 17/27). This last result is plausible given that jumping over fences generally takes place during foot chases.

Finally, 5% of the cases occurred **when carrying an object** (a total of 26/547 cases), half of them during activities other than police interventions (Table 26). This percentage may, however, be considered relatively low, particularly since it is no higher than that for cases not otherwise specified (5%, 27/547) and for which the description was insufficiently detailed to identify a possible activity-related factor.

B.1.3.2 Environment

The most frequent environmental risk factor for the STFs was icy/snowy ground. It was involved in 42% (228/547) of all the STF accidents/incidents (Table 27). However, other environmental risk factors were also important, but for different reasons, depending on the type of accident/incident.

One of the most frequent environmental risk factors for 'Slips, trips, losses of balance with/without fall' was **icy/snowy ground**, which accounted for 47% of the cases (172/367, Table 27). The conclusions drawn from the results specific to slip accidents and presented in Section 3.2.1 of this report may also be applicable here since in 97% of the cases where icy/snowy ground was a factor (165/172, see Table 12 and Table 27), a slip was involved (rather than any other type of loss of balance). These conclusions are that **parking lots and icy/snowy walkways near the police station** (35%, 61/172 cases of slips, trips, losses of balance with/without fall where icy/snowy ground was a factor) and the **lack of visual cues** (ice not visible) are major factors. A second environmental factor is the **uneven terrain, hole, sidewalk/change in level** factor (20%, 74/367, Table 27). This includes forests, wooded areas, mountains, and areas near rivers or railways, which are associated with uneven terrain (9%), holes in the road (7%), and sidewalks and other changes in level outside (4%). Uneven terrain was a bigger factor at PD 3, whereas holes and sidewalks were a bigger factor at PD 1 (results not presented in this report). In addition, 36% of these events took place during running (27/74, Table 27).

[14] SPVM – Service de police de la Ville de Montréal, 2010. Joint-committee section (occupational health and safety). Personal communication.

Table 27 Distribution of the STFs, by environmental risk factor for each type of accident/incident, among the police officers in the three departments studied during the 2007–2009 period

Type of accident/incident	Slip, trip, loss of balance with/without fall				Fall in a STAIRWAY or on steps				Fall when getting into/out of stationary vehicle			Fall when JUMPING over or CROSSING …			Aggregate TOTAL
Environment General location	-	Running	Transport-ing objects	TOTAL	-	Running	Transport-ing objects	TOTAL	-	Transporti ng objects	TOTAL	-	Running	TOTAL	
Icy/snowy ground	**138**	**23**	**11**	**172**	**28**			**28**	**22**	**3**	**25**	**3**		**3**	**228**
Various outdoor locations	*84*	*22*	*5*	*111*	*24*			*24*	*19*	*3*	*22*	*3*		*3*	*160*
Near the police station	*54*	*1*	*6*	*61*	*4*			*4*	*3*		*3*				*68*
Uneven terrain/hole/sidewalk/change in level	**46**	**27**	**1**	**74**	**2**			**2**	**1**		**1**	**5**	**8**	**13**	**90**
Various outdoor locations	*41*	*26*	*1*	*68*	*2*			*2*	*1*		*1*	*5*	*8*	*13*	*84*
Near the police station	*5*			*5*											*5*
n.s.		*1*		*1*											*1*
Stairway, steps					**49**	**1**	**5**	**55**	**6**	**1**	**7**				**62**
Various outdoor locations					*12*	*1*	*1*	*14*	*6*	*1*	*7*				*21*
Near the police station					*2*			*2*							*2*
Various indoor locations					*18*			*18*							*18*
Inside the police station					*3*		*1*	*4*							*4*
n.s.					*14*		*3*	*17*							*17*
Wet surface	**7**	**2**		**9**	**29**			**29**	**1**		**1**				**39**
Various outdoor locations		*2*		*2*	*10*			*10*							*12*
Near the police station	*1*			*1*					*1*		*1*				*2*
Various indoor locations	*1*			*1*	*15*			*15*							*16*
Inside the police station	*5*			*5*											*5*
n.s.					*4*			*4*							*4*
Person	**24**	**4**	**1**	**29**											**29**
Various outdoor locations	*4*	*4*		*8*											*8*
Various indoor locations	*1*			*1*											*1*
Inside the police station	*18*			*18*											*18*
n.s.	*1*		*1*	*2*											*2*
Structure, hedge	**9**	**2**		**11**								**2**	**8**	**10**	**21**
Debris, rocks, or other materials on the ground	**6**	**2**		**8**											**8**
Object, equipment	**2**	**1**	**1**	**4**									**1**	**1**	**5**
Poor visibility	**2**	**1**		**3**	**2**			**2**							**5**
Vehicle	**1**	**2**	**1**	**4**											**4**
Dirty surface	**1**			**1**	**1**			**1**							**2**
Change in level indoors	**1**	**1**		**2**											**2**
Furniture	**2**			**2**											**2**
Animal	**2**			**2**											**2**
Access ramp	**1**		**1**	**2**											**2**
Inadequate footwear		**1**		**1**											**1**
Wind	**1**			**1**											**1**
Environment not specified	**22**	**19**	**1**	**42**					**2**		**2**				**44**
Aggregate TOTAL	**265**	**85**	**17**	**367**	**111**	**1**	**5**	**117**	**32**	**4**	**36**	**10**	**17**	**27**	**547**

* n.s. = not specified

Another factor that emerged from the results was the involvement of another person, i.e. the fact of being struck or pushed by someone, being dragged along by someone, or losing one's balance or falling because of another person. This factor played a role in 8% of the cases (29/367, Table 27). These cases, not regarded as altercations, occurred mostly (19 cases) during training, particularly during police officer/suspect role plays. These results are relatively marginal, given that if altercations had been included in the analysis of the STFs, they would have totalled 130 cases of accidents/incidents (see Appendix A).

For falls when jumping over or crossing an obstacle, it is often **uneven terrain** that was involved (48%, 13/27, Table 27), and of course, the obstacle itself, such as **a structure or hedge** (37%, 10/27, Table 27). For this type of accident/incident, running was also a factor in the majority of cases (62%, 8/13, Table 27).

For falls in a stairway, while the steps themselves represent a risk factor (in 47% of the cases, 55/117, it was the main factor, Table 27), **wet surfaces** and **icy/snowy ground** also represent major risk factors (nearly 25% of the cases each). Table 28 shows the detailed results for falls in a stairway or on steps.

Table 28 Distribution of the number of *falls in a stairway*, by environmental risk factor, for the police officers in the three departments studied during the 2007–2009 period

Environment *Specific type of accident/incident*	**Fall in a STAIRWAY or on steps**			
	Outside	**Inside**	**Not specified**	**TOTAL**
Stairway, steps	**16**	**22**	**17**	**55** ***47%***
stairway, steps (not otherwise specified)	*10*	*18*	*13*	*41*
step gave way	*3*	*0*	*1*	*4*
carrying an object	*1*	*1*	*1*	*3*
narrow steps	*0*	*0*	*1*	*1*
going up a set of steps	*1*	*0*	*0*	*1*
defective ramp	*0*	*0*	*1*	*1*
twisted a foot	*1*	*0*	*0*	*1*
boot got caught	*0*	*1*	*0*	*1*
defective step	*0*	*1*	*0*	*1*
going up a down escalator	*0*	*1*	*0*	*1*
Wet surface	**10**	**15**	**4**	**29** ***25%***
Icy/snowy surface	**28**			**28** ***24%***
Hole	2			2
Poor visibility	1	1		2
Dirty surface		1		1
Total	**57**	**39**	**21**	**117** ***100%***

Generally speaking, several of the tendencies observed in the results for slips and presented in Section 3.2.1 of this report are also observed here because 65% of the falls that occurred in a stairway (76/117, see Table 12 and Table 27) involved a slip (in nearly all cases on wet, icy/snowy, or dirty surfaces). For all the STFs in a stairway, the tendencies observed were that 49% of the events (57/117, Table 28) took place outside and nearly half of them on icy/snowy steps (28 cases). In 33% of the cases (26/76, Table 13), the accidents/incidents took place inside, with some of them (15 cases) occurring on wet steps mostly caused by footwear that was wet due to rain or snow. Where the difference between the results for the two sets of data (slips only in the body of this report and all STF events in this appendix) was most pronounced was in the bigger proportion of the **stairway/steps** factor for all STFs: it accounted for 47% (55/117, Table 28) of the STF events compared to 38% of the slip events (29/76, Table 13). While the majority of the event descriptions were not sufficiently detailed to signal any one factor in particular (41/55 cases), some pointed to various factors that could be involved, as, for example, a step that gives way (4 cases) or carrying objects (3 cases) (Table 28).

B.2 Results for the school crossing guards

B.2.1 Frequency and severity of the STFs, by gender, age, and date of event

The total number of STFs was compiled for the school crossing guards in the two cities studied. The annual frequency of accidents/incidents compared to the number of school crossing guards on staff, as well as the severity of the accidents involving loss of work time that occurred during the three-year period, are presented by gender in Table 29 and by age in Table 30.

Table 29 Frequency (a) and severity (b) of STF events among the school crossing guards in the two cities studied, by gender, during a three-year period (2007–2009 for City 1 and 2008–2010 for City 2)

a) Annual frequency of events with and without loss of work time

Gender	Average no. of workers/yr.	Average no. of STFs/yr.	%
F	597 (63%)	16.7 (81%)	**2.8**
M	352 (37%)	4.0 (19%)	**1.1**
TOTAL	949 (100%)	20.7 (100%)	**2.2**

b) Severity of accidents involving loss of work time that occurred during the three-year period

Gender	No. of accidents with loss of work time	Average absence duration [days]	Median absence duration [days]
F	32	113.3	19.0
M	8	38.0	18.5
TOTAL	**40**	**98.3**	**19.0**

Table 30 Frequency (a) and severity (b) of STF events among the school crossing guards in the two cities studied, by age, during a three-year period (2007–2009 for City 1 and 2008–2010 for City 2)

a) Annual frequency of events with and without loss of work time

Age	Average no. of workers/yr.	Average no. of STFs/yr.	%
18-59	471 (50%)	12.3 (60%)	**2.6**
60+	478 (50%)	8.3 (40%)	**1.7**
TOTAL	949 (100%)	20.7 (100%)	**2.2**

b) Severity of accidents involving loss of work time that occurred during the three-year period

Age	No. of accidents with loss of work time	Average absence duration [days]	Median absence duration [days]
18-59	26	105.0	19.0
60+	14	85.7	15.5
TOTAL	**40**	**98.3**	**19.0**

Over a three-year period, 2.2% of the school crossing guards in the two cities studied were involved in an STF accident/incident annually, according to the data collected. Accidents involving loss of work time represented 62% of all the events (see Table 1). These accidents resulted in an average absence duration of 98.3 days and a median absence duration of 19 days.

Proportionately speaking, STF events occurred more frequently among the women during the study period in the two cities studied, with 2.8% of them affected compared to 1.1% of the men.

With respect to age, the largest number of school crossing guards affected by an STF event were in the 59 years and under age group (2.6%) compared to (1.7%) among those in the 60 years and over age group.

It is difficult to discern any clear tendency in accident severity by either age group or gender. In fact, the number of events was small and variable from year to year. In addition, four cases out of the 40 accidents analyzed had a particularly high average absence duration of 629 days (three women in the 59 years and under age group and one woman in the 60 years and over age group).

Figure 11 shows the number of events that occurred during the three-year study period among the school crossing guards, by month of the year. Event frequency was highest in the winter months, particularly December, February, and March, which accounted for 50% of the cases. The number of cases occurring in December was especially high if one considers that this month has fewer weeks of activity than the other months of the school year.

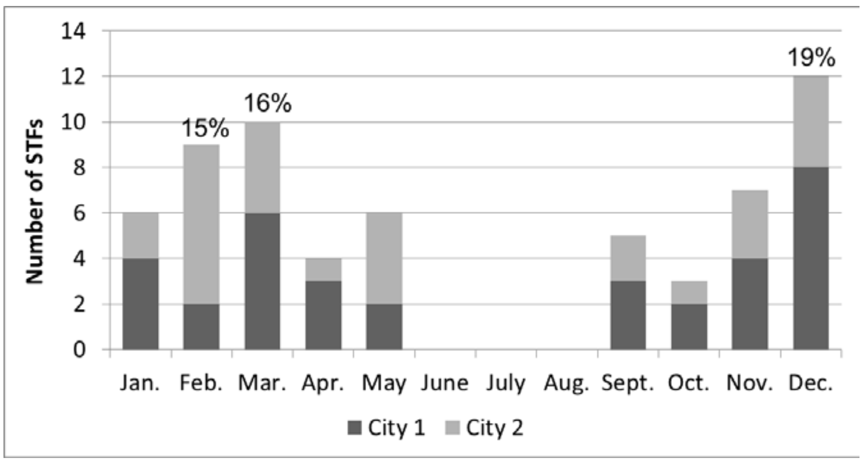


Figure 11 Distribution of the number of STFs that occurred among the school crossing guards in the two cities studied, by month of the year, during a three-year period (2007–2009 for City 1 and 2008–2010 for City 2)

B.2.2 Distribution of the STFs, by type of accident/incident

The distribution of the types of accidents/incidents that occurred during three consecutive years among the school crossing guards in the cities studied is shown in Table 31. Most of the cases (98%, 61/62) involved slips, trips, and losses of balance, either with a fall (68%) or without a fall (31%). Only one case consisted of a fall on steps (when entering the school for a break, the worker was hit by a door that was opening and the steps were icy). With regard to the specific types of accidents/incidents, nearly half of them involved 'Slipping on a surface' (45%, 28/62 cases). The other specific types of accidents/incidents were 'Tripping' (16%, 10/62 cases), 'Twisting a foot' (6/62 cases), 'Being hit by a vehicle' (5/62 cases), and 'Stepping into a hole' (4/62 cases). Overall, the event profile was similar in both cities.

Table 31 Distribution of the STFs, by *general* and *specific* types of accident/incident, among the school crossing guards in the two cities studied during a three-year period (2007–2009 for City 1 and 2008–2010 for City 2)

Type of accident/incident	Slip, trip, loss of balance with/without fall		Fall in a STAIRWAY or on steps	Total	
	With a fall	Without a fall			
Slipping on a surface	24	4		28	***45%***
Tripping	10			10	***16%***
Twisting a foot	1	5		6	
Being hit by a vehicle	1	4		5	
Stepping into a hole	3	1		4	
Losing balance		2		2	
Being struck or pushed by a pedestrian, a door…		1	1	2	
Losing footing	1	1		2	
Falling (not otherwise specified)	1			1	
Stepping into midair	1			1	
Taking an awkward step		1		1	
Total	**42** ***68%***	**19** ***31%***	**1**	**62**	***100%***
Aggregate TOTAL	**61** ***98%***		**1**	**62** ***100%***	

B.2.3 Distribution of the STFS by the various extrinsic risk factors

B.2.3.1 Activities/tasks

Overall, the majority of events (89%, 55/62 cases) occurred during school crosswalk activities (Table 32). However, the event descriptions were limited, allowing only the following findings: in 56% of the cases (31/55), the event occurred when taking children across the crosswalk (16 cases), when returning to the intersection after taking children across (7 cases), when going to get children (6 cases), or when waiting at the intersection (2 cases). For the other 44% of the cases (25/55), no details were mentioned other than the fact that the school crossing guard was at his intersection at the time the event took place. A few cases (6) occurred during activities other than school crosswalk activities (Table 32).

B.2.3.2 Environment

Icy/snowy ground was the most frequent environmental risk factor among the school crossing guards (Table 33) for both of the cities studied. It was involved in 56% (35/62) of the STF accidents/incidents. In most of these cases (89%, 31/35), it was specifically the road or the sidewalk near the school crosswalk that was icy or snowy.

Table 32 Distribution of the STFs, by type of activity/task for each type of accident/ incident, among the school crossing guards in the two cities studied during a three-year period (2007–2009 for City 1 and 2008–2010 for City 2)

Type of accident/incident / Type of activity/task	Slip, trip, loss of balance with/without fall	Fall in a STAIRWAY or on steps	TOTAL
School crosswalk activity	**55**		**55**
Being at the intersection, not otherwise specified	24		24
Taking children across the crosswalk	16		16
Returning to the intersection after crossing	7		7
Going to get children	6		6
Waiting at the intersection	2		2
Other activity	**6**	**1**	**7**
Break	2	1	3
Outside working hours	2		2
Retrieving a ball	1		1
Taking photographs of students	1		1
Aggregate TOTAL	**61**	**1**	**62**

Table 33 Distribution of the STFs, by environmental risk factor and type of activity/task for each type of accident/incident, among the school crossing guards in the two cities during over a three-year period (2007–2009 for City 1 and 2008–2010 for City 2)

Type of accident/incident / **Environment** Type of activity/task	Slip, trip, loss of balance with/without fall	Fall in a STAIRWAY or on steps	Aggregate TOTAL
Icy/snowy ground	**34**	**1**	**35**
School crosswalk activity	*31*		*31*
Other activity	*3*	*1*	*4*
Sidewalk/hole	**10**		**10**
School crosswalk activity	*10*		*10*
Vehicle	**6**		**6**
School crosswalk activity	*6*		*6*
Debris, rocks, or other materials on the ground	**2**		**2**
School crosswalk activity	*1*		*1*
Other activity	*1*		*1*
Animal	**1**		**1**
School crosswalk activity	*1*		*1*
Person (pedestrian)	**1**		**1**
School crosswalk activity	*1*		*1*
Wind	**1**		**1**
School crosswalk activity	*1*		*1*
Structure (wall)	**1**		**1**
School crosswalk activity	*1*		*1*
Environment not specified	**5**		**5**
School crosswalk activity	*4*		*4*
Other activity	*1*		*1*
Aggregate TOTAL	**61**	**1**	**62**

The second most frequent environmental risk factor was the presence of **sidewalks/holes**, which accounted for 16% of all the events (10/62, Table 33). In seven of these cases, the school crossing guard tripped, twisted a foot, or fell when stepping onto or off the sidewalk. In the three other cases, the guard twisted a foot when stepping into a hole in the road.

B.3 Summary

STF accidents/incidents occurred among 1.8% of the police officers and among 2.2% of the school crossing guards annually during the three-year period studied. The average absence duration for accidents involving loss of work time was 59.5 days for the police officers (median duration of 17.5 days) and 98.3 days for the school crossing guards (median duration of 19 days).

STF events occurred more frequently among the women than the men in both groups. For the police officers, it was the 18- to 34-year age group that was most frequently affected by this problem, but accident severity was greater among the 45 years and over age group. For the school crossing guards, it was those in the 59 years and under age group who were most affected, but no tendency was observed for accident severity. There were more STF events during the winter months in both groups.

For the police officers, the most frequent secondary environmental risk factors associated with STFs were:

- **icy/snowy ground**, which was involved in 42% of all cases (228/547). This was especially a major factor for slips, trips, and losses of balance with/without a fall (47% of the cases, 172/367) and for falls when getting into/out of a vehicle (69% of the cases, 25/36);
- **icy/snowy parking lots and walkways near the police station,** which accounted for 35% of slips, trips, losses of balance with/without a fall where icy/snowy ground was a factor, (61/172);
- **uneven terrain, holes, sidewalks/change in level,** which were involved in 20% of slips, trips, and losses of balance with/without a fall (74/367), and in 48% of falls when jumping over or crossing an obstacle (13/27);
- for falls in a **stairway**, while the steps themselves represent a risk factor (in 47% of the cases, 55/117, it is the main risk factor), icy/snowy ground and wet surfaces also constitute major risk factors (approximately 25% each);
- **lack of visual cues** was also a noteworthy factor.

The most frequently involved activities/tasks were:

- all types of **police interventions**, particularly calls (patrol), which represented 63% (343/547) of all the STF cases.
    - **other activities** requiring fewer interactions with the public, such as entering/leaving the police station or getting into/out of the patrol vehicle, or

arriving at/leaving work, also presented some risk, given that these were the activities being performed at the time of the event in 32% (177/547) of the cases;

- **running**, mainly during foot chases, accounted for 19% of all the events (103/547). This was a particularly important factor in falls that occurred when jumping over or crossing an obstacle (63% of these cases, 17/27), and in slips, trips, and losses of balance with/without a fall (23% of these cases, 85/367). In addition, running was an important factor when uneven terrain/holes/sidewalk/change in level were reported;
- **carrying objects** was also a factor, but to a lesser degree. It accounted for 5% (26/547) of all the STF cases.

For the school crossing guards, the most frequent environmental risk factors and activities/tasks were:

- **icy/snowy ground**, which was involved in 56% (35/62) of all the STF events;
- **sidewalks and holes**, which were involved in 16% of the cases (10/62);

The type of activity/task most frequently performed during the event was school crosswalk activities, which were involved in 89% of the cases (55/62).

APPENDIX C: FOOTWEAR COMMENTS EXTRACTED FROM THE EVENT DESCRIPTIONS

Table 34 Comments made by the police officers and school crossing guards on boots/footwear, extracted from the statistical analysis in Appendix B concerning STF events, and distribution by environmental risk factor (slip events shown in black font; other STF events shown in grey font)

Police officers		**Total number of cases**
Environmental factor	**Comments on boots**	**26**
Inadequate footwear	Lost footing because of our boots, which are not designed for running	1
Icy/snowy ground	Wearing Prospector Gore-Tex boots supplied by the department (in some cases, in virtually new condition)	5
	Wearing worn boots, cleats gone	1
	Analysis: one of the factors may be attributed to the boots worn by the employee. Prevention: have footwear adapted to the weather	1
	Corrective measure: wear overshoes at all times, when supplied	1
	Using cleated soles or an abrasive would have prevented the accident	1
Stairway, steps	My boot got caught.	1
	Wearing Prospector Gore-Tex boots supplied by the department	1
Person	Analysis: wearing high boot might have lessened the shock	1
Wet surface	Boots/shoes or overshoes wet or snowy	12
Uneven terrain	Wearing Prospector Gore-Tex boots supplied by the department	1
School crossing guards		**Total number of cases**
Environmental factor	**Comments on boots**	**2**
Icy/snowy ground	Cleats couldn't get a grip: While I was working, I hit a patch of ice before stepping onto the icy sidewalk. There was an incline. My cleats couldn't get a grip. I lost my footing as I fell and I hurt my leg."	1
	Wearing cleated boots: "I was stepping down off the curb and I twisted my left ankle. The road was icy and I was wearing my cleated boots."	1