THE EFFECT OF ANTI-SLIP DEVICES ON PEDESTRIAN SAFETY DURING WINTERTIME

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INTRODUCTION

The analysis of injuries sustained in pedestrian accidents has to a large extend been focused on collision accidents with vehicles. The knowledge about pedestrian risk has therefore also primarily been related towards vehicles and how pedestrians are exposed to vehicles. Very little is known about pedestrian exposure. The statistics for traffic accidents is mainly based on police reported vehicle accidents and only rarely are also hospital-reported accidents the basis of analysis. Through hospital based statistics it has become obvious that vulnerable road-users, especially pedestrians, are injured much more frequently in the traffic environment than what police-reported traffic accident data shows. Here the term single-pedestrian accident will be used for accident with injuries that occur among pedestrians without any other road-user involved.

Hospital-based injury statistics from Sweden clearly show a high frequency of injuries from single-pedestrian accidents on slippery surfaces, i.e. on ice and snow. Annually, 25 - 30 000 people (3.2 per 1000 inhabitants) need medical care for treatment of injuries from falling on ice and snow (Nordin, 2003). Data based on The European Home and Leisure Accident Surveillance System - EHLASS 2003 estimates an average of 1.4 injuries /1000 inhabitants and 4.2 for the age group 65-74 years in Sweden (Socialstyrelsen, 2005).

Similar conditions occur in other countries with seasonal variations such as Finland, Norway, Canada, USA and Japan. More than 100,000 pedestrians in the Nordic countries are every winter expected to receive medical treatment due to winter weather and slippery conditions (based on estimations from Nordin, 2003; Kelkka, 1995 and Perälä et al, 2001).

Background

Pedestrians out-door activities during wintertime

The risk of an injury reduces the interest in engaging in outdoor activities during the wintertime. A study of five municipalities in Sweden during the winter 1999/2000 shows that people reduce their outdoor walking during the wintertime (Wretling, 2002). In total, 8% of people never, or nearly never, walk outdoors during the wintertime, with a slightly larger portion of males stating this compared to females. As many as 38% state that they seldom, nearly never or never walk outdoors during the winter. Slippery road conditions and snowfalls are the two most common reasons for elderly people (>65 years old) to cancel an outdoor walking trip during the wintertime. After a fall, 20% state that they go outdoors much less frequently, up to several months after the fall (Öberg et al, 1996).

Injuries from single-pedestrian accidents during wintertime

In a road surface study and exposure measurement 1994 in three municipalities in Sweden the injury rate was 2/1000 inhabitants or 7.2/1,000,000 person kilometres. Of all the single-pedestrian accidents, 17-30% was treated as in-patient. Of all injured pedestrians, 78% considered the condition of the surface to be significant to the fall, especially all icy and snow-covered road conditions. The days with mixed road conditions, i.e. bare ground mixed with icy and snowy conditions, were six times more dangerous than summer conditions, and the days with only ice and snow conditions were eight times more dangerous. (Öberg et al, 1996). The negative effects regarding the safety of single pedestrians, and also the effect on length of in-patient days, has also been found by Berntman (2003) and Larsson (2002). In-patient time is longer for elderly pedestrians (>65 years) in single-pedestrian accidents on snow/ice than on other surfaces. They accounts for half of the in-patient time, but only one-third of the injuries (Larsson, 2002). Older women are generally more active compared to older men. Their bones are also more brittle and get injured more easily (Pasikowska, 1998).

There are similar problems in other countries with icy and snowy winter roads. The total number of pedestrians taken by ambulance because of fall-related winter accidents on the Hokkaido island, Japan, has increased from 120 in 1984 to 503 in 1994 and 831 in 2004 (Takahashi et al, 2007). With the largest portion of injuries occurring in the city of Sapporo, Hokkaido island, where 111 people were brought to hospital because of slip and falling accidents in December 1987 (Hara et al, 1991), 248 in December 1992 (Takamiya et al, 1997) and as many as 351 in December 2001 (Shintani et al, 2003b). The severity of the injury increases with age. The teen age group accounts for less then 5% and the age group 60-79 accounts for about 40% of the injured fallers in Sapporo (Hosotani et al, 2007).

Different measures to reduce injuries from single-pedestrian accidents during wintertime

Injuries from accidents when walking on snow/ice can be greatly reduced by increasing the friction which reduces the risk of slipping and sliding (Nilsson, 1986), or by applying other countermeasures related to the individual or related to winter maintenance. Examples of winter maintenance measures are providing protective roofs over sidewalks and bus stops, heating the ground surfaces where people walk, make sure there is adequate snow clearance and simultaneous gritting/sanding or salting and sometimes just gritting/sanding when there is no new snowfall. Examples of measures related to individual people are providing transport services for the elderly, information on the risk for slipperiness, recommending or providing adequate winter footwear and/or anti-slip devices that can be mounted on shoes (Nilsson, 1986).

Still, there is no conclusive study showing the benefits of using anti-slip measures, such as snow removal, anti-slip treatment or the use of personal safety equipment like individual anti-slip devices (Öberg et al, 1996; Elvik, 2000). One study (Shintani et al, 2002) verifies that spreading gravel up to 167 g/m^2 enhanced the sense of security more than using anti-slip shoes even if measurements showed that the coefficient of dynamic friction (CODF) was not improved by spreading that amount of gravel.

Effects of anti-slip devices

Grönqvist and Hirvonen (1995), Gao (2001), Abeysekera and Gao (2001) and Gao et al (2003) have been studying the performance of winter footwear on snow/ice surfaces. Studies have been made on pedestrian injuries on ice and snow and also somewhat on the use of anti-slip devices indicating increased friction and reduced slipperiness (Merrild and Bak, 1983; Bruce et al, 1986). Work-related injuries from slip and fall accidents on ice and snow are also a large problem in several countries, among several different occupations such as postal delivery workers (Bentley and Haslam, 1996, Bentley and Haslam, 1998 and Haslam and Bentley, 1999), home helpers (Kemmlert and Lundholm, 2001), drivers, getting in and out and during delivery, as well as teachers, childminders, and others needing to walk outdoors at times during working hours (AFA Insurance, 2006).

A study among women living in Sapporo, Japan, showed a relatively high experience in falls requiring medical attention. The anti-skid performance of their shoes and their experiences from anti-slip devices were recorded, with 16.3% (N=1382) having detachable anti-slip soles and 38% had non-slippery performance, including 16.3%, with pins, knobs and ceramics (similar to sandpaper) on the soles (Hara et al, 1997). No evaluation of the performances of the devices is recorded.

However evidence of association between the use of anti-slip devices and prevention from slipping and falling is slowly growing. An intervention study was conducted in the USA during the winter 2003/2004 among 101 fall-prone subjects aged 65 and older. The subjects were randomized to wear an anti-slip device or their ordinary winter footwear outdoors. It is concluded that wearing the specific anti-slip device may reduce the risk of outdoor winter falls, and of non-serious injurious falls in older community-dwelling people with a history of previous falls (McKiernan, 2005).

Of a total of 93 subjects, 63 female and 30 male, 64 subjects used anti-slip devices and 29 used studded shoes. The subjects (aged 20 - 80) were exposed to three fall accidents. Anti-slip devices or studded shoes were used in one of these three cases. They were also exposed to eight “close to” fall accidents where anti-slip devices were used in three of the cases, studded shoes in two cases and ordinary shoes in three cases (Juntunen and Grönqvist, 2005, Juntunen et al, 2005). No comparison to non-users was made and the exposure was not registered.

As shown above, injuries caused by falls on slippery surfaces are frequent, i.e. the maintenance of pathways is insufficient. Still, the safety is dependent on the individual and his/her ability, the shoes they wear, anti-slip devices and their interaction with the specific surface, and access to information about the slip properties. Using appropriate winter footwear and anti-slip devices on shoes are essential measures to prevent a person from slipping and falling on ice and snow (Grönqvist and Mäkinen, 1997). It is suggested that anti-slip devices are expected to reduce the frequency of falls and injuries, which is one of the hypothesis tested below.

Quality assessment of anti-slip devices

Anti-slip devices are regarded as personal protective equipment (PPE). The Maastricht agreement, article 129a, states that consumer products must not cause damage to persons and property. Personal protective equipment, such as anti-slip devices, has special legislation to regulate that the manufacturer or distributor of the product is responsible for the safety of the equipment. This is done without any specific standard. The anti-slip devices are assessed directly against the essential health and safety requirements stipulated in the Council Directive 89/686/EEC (Grönqvist and Mäkinen, 1997). As an essential part of the EC type-examination process, appropriate tests deemed necessary to show conformity to the basic health and safety requirements of the PPE Directive (89/686/EEC) should be carried out to check the conformity of PPE. The European standards have been developed to devise practical solutions for harmonize these essential requirements. This has not yet been made for anti-slip devices.

The aim and scope of this work

This study focus on preventing from slips and falls outdoor during wintertime thus reducing injuries from single-pedestrian accidents. The studies are made on the properties of anti-slip devices, their effect on exposure and their effect on the risk of slipping and falling. The aim of this work is to develop knowledge regarding walking safety for pedestrians during the wintertime:

- *How can anti-slip devices be tested?*
- *How can more effective anti-slip devices be developed?*
- *Do anti-slip devices improve walking ability and safety*

SCIENTIFIC PERSPECTIVE

Traffic safety research

In traffic safety research it is assumed that serious conflicts (dangerous situations), involving two or more road users, are related to real accidents (Hydén, 1987). It is assumed in the same way that there are events that almost end up as near accidents (Svensson, 1998). In a safety hierarchy these situations are found at a lower level and further down in that hierarchy it is found “almost almost near-accidents” (See Figure 1). Therefore by studying the impact of different countermeasures in the traffic environment on the ratio of near accidents or of “almost almost near-accidents” it is possible to assume the effect on the ratio on real accidents (Svensson, 1998). In this work a similar assumption is made. Injured in single-pedestrian accidents during wintertime are expected to be a small portion of people falling on slippery surfaces outdoors during wintertime and those falling are a expected to be fraction of those slipping. Thus by studying the process of slipping and eventually the process of falling it is possible to make assumption about injuries from single-pedestrian accidents during wintertime.

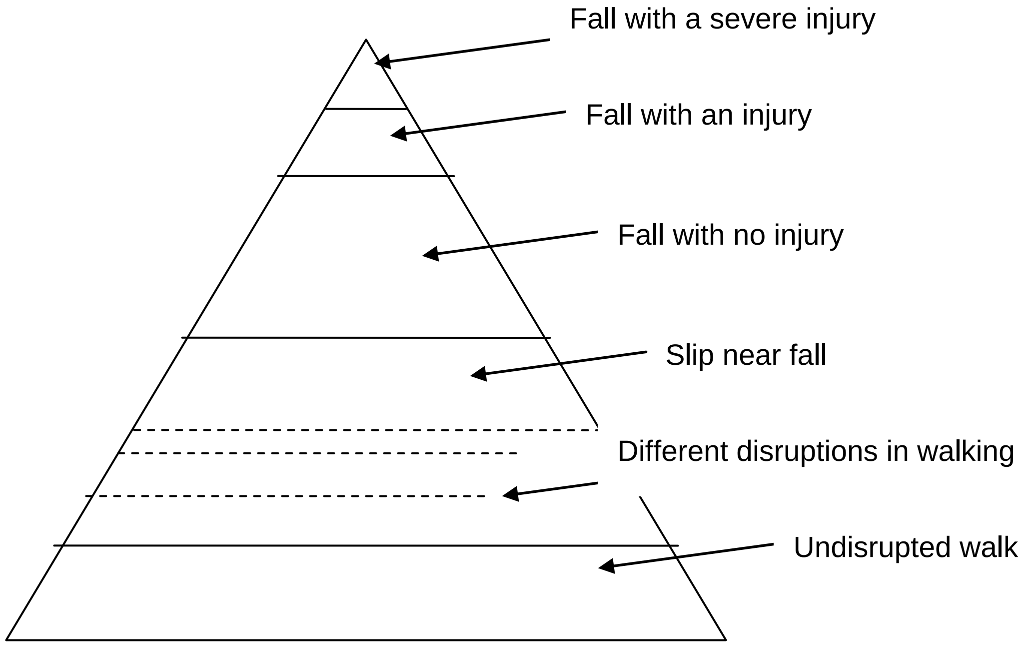

Figure 1. *Schematic relations between different events among pedestrian walk during wintertime ranging from injuries, via dangers situations and incipient danger down to normal walking (Based on Hauer 1997, Hydén 1987 and Svensson, 1998).*

Slip mechanism and friction

Loss of balance is the event common to falls, and the factor that most often triggers a single-pedestrian accident. During wintertime the loss of balance among those injured in single-pedestrian accidents is mostly related towards slipping therefore the relation between slipping, fall/no fall and when falling injury/no injure are of interest in a preventive perspective.

On a more detailed level the most critical moments in the human gait are the heel strike and the toe-off (Grönkvist et al, 1989; Strandberg and Lanshammar, 1981). The primary risk factor for slipping accidents, according to Grönqvist (1995), is poor grip and low friction between the footwear (foot) and the underfoot surface (pavement). The heel contact is considered more challenging for stability and more hazardous from the slipping point of view than the toe-off phase, since forward momentum maintains the body weight on the leading foot causing a forward slide of the foot (Redfern et al., 2001). A gentle heel landing also reduces collision-forces in the shoe/surface interface during weight acceptance, a factor important in maximizing friction and slip resistance in water, oil and snow (Grönqvist, 1999). A low coefficient of friction (COF) is a necessity for the slip to occur. Especially when the friction is too low and the heel starts to slide and the sliding distance tends to be too long, the balance gets lost and a fall occurs. The sliding distance before the balance gets lost is age dependent. The older the person, the shorter the sliding distance before balance is lost. Different countermeasures can be used to prevent a person from slipping and sliding. Anti-slip devices are one such individual countermeasure.

COF limit values can be correlated to the normal variability of the human gait, since walking speed, stride length, anthropometric parameters, etc., may greatly affect the friction demand during motion (Carlsöö, 1968; Andres et al., 1992). Subjective evaluations of friction have been assessed in some studies with normal ‘winter’ shoes and these evaluations have been compared to ‘objective’ measurements (Grönqvist et al., 1989 and Gao 2001). In the test by Gao (2001) the tendency to slip was registered in a scale from 1 to 5, where 1 means very high tendency to slip and 5 means very low tendency to slip as evaluated by the subjects. The subjective rating was compared to objective COF. There is a significant correlation between subjective ratings of tendency to slip and objective COF measurements ($r=-0.900$, $p=0.037 < 0.05$). Studies among 40 healthy industrial workers on Perceived Sense of Slip (PSOS) and COF show a slightly lower PSOS compared to COF (Chiou et al, 2000). A study assessing floor slipperiness indicates that both objective and subjective measures of slipperiness are important in field studies and that an average friction coefficient and subjective perceptions may agree well with each other and that both might be good indicators of slipperiness (Chang et al, 2004 and Chang et al, 2006). Subjective methods, such as perceived safety and perceived balance, can therefore be used for assessing the risk for slips and falls.

Research for prevention

The Haddon matrix has been in use for several decades in guiding research and in the development of interventions both in public health but also in traffic safety. For injuries from single-pedestrian accidents involving slips and falls during wintertime the matrix is presented in Table 1.

Table 1. *Anti-slip devices (Based on the Haddon matrix; Haddon, 1980)*

Element	Phases		
	Before fall	In fall	After fall
Human (inherent)	Information Training Education Behaviour (e. g. drinking and walking) Attitudes		Emergency Medical service
Shoe/anti-slip devices	Primary safety Exposure Speed	Secondary safety Slipping, sliding, falling	Recover
Road (external)	Local climate Surface condition (Evenness, friction,…)	Roadside safety Obstacle to fall into/on	Restoration of road surface Anti-slip treatment

The factors defined by the rows in the matrix refer to the interacting factors that contribute to the injuring process. The human represent the behavioural and physical element. The shoe represents the means for transport and also in this study the carrier of the measure to improve safety and the road represents the variable external conditions.

It is then evident based on the Haddon matrix that the individual, the interaction and the environment need to be studied, to be able to describe the different preventive factors that could be applied to prevent falls and injuries in single-pedestrian accidents. That is, intrinsic, interaction as well as extrinsic factors needs to be studied or registered, see Figure 2.

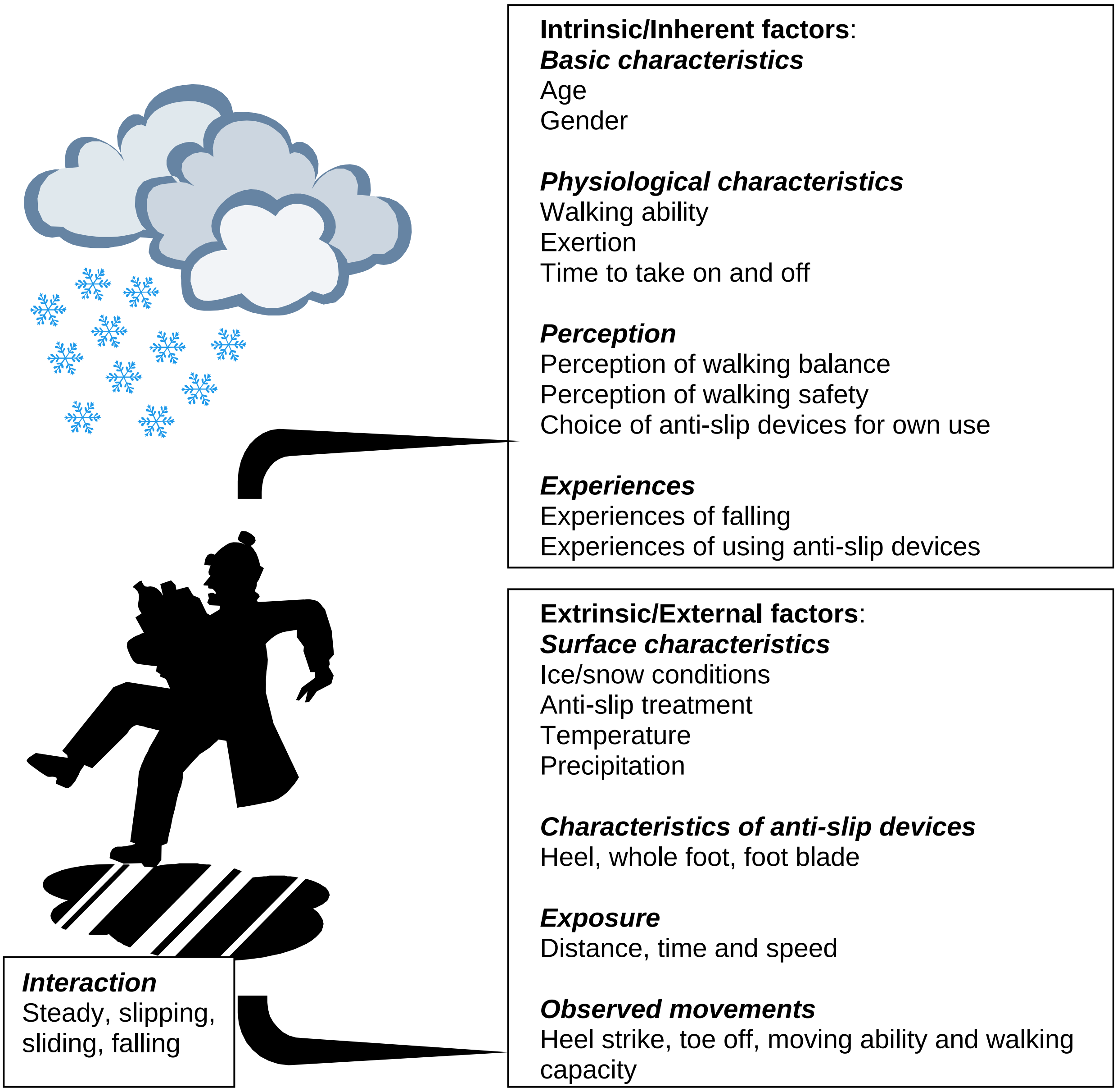

Figure 2. *Intrinsic and extrinsic factors of pedestrians on icy surfaces during wintertime.*

METHODS AND MATERIAL

Order and contents of the tests

Tests were conducted on seven different occasions (Test 0, Test A-F) to develop the test method, test anti-slip devices, assess the test method, and to analyse the benefits of using anti-slip devices, see Table 2.

Table 2. *Order and content of the tests.*

Test	Month/ Year	Purpose	Participants		Number of tested anti-slip devices	Variables	Comments
			Total number (M/F)	Ages (year)			
0	February 1992	Development of test procedures	10 (5/5)	55-80	4	See list below*	
A	February 1993	Laboratory test (Consumer test)	4 (2/2)	60-65	19	The same variables	
B	March 1994	Laboratory test (Consumer test)	4 (2/2)	60-65	8	The same variables	Same subjects as in A. Two devices had been tested before
C	March 1995	Laboratory test (Consumer test) and evaluation of the test method	4 (2/2)	60-65	6	The same variables	Same subjects as in B. Two devices had been tested before
D	March 1996	Laboratory test (Consumer test) and evaluation of the test method	4 (2/2)	60-65	5	The same variables	Same male subject as in B. One device had been tested before
E	Nov-Dec 2002	Laboratory test Benchmarking of test procedure. Comparison with tests at FIOH	107 (46/61)	22-80	3	The same variables +Walking time	The devices were also tested at FIOH*
F	Feb-April 2008	Field study Intervention study	61 (34/37)	27-67	3		Same type of devices as in E

**The subject's perceived walking safety and balance, analyses from video recordings of walking postures and movements, time to take on and off anti-slip device, perceived advantages and disadvantages for each anti-slip device, and a priority list for personal use according to three criteria – safety, balance and appearance.*

The number of subjects varied between the tests. From the beginning (Test 0), 10 randomly selected subjects, half female and half male, participated in the development of the test method. Four anti-slip devices were chosen representing three different designs of anti-slip devices available on the Swedish market: heel device, foot blade device and whole-foot device (Gard and Lundborg, 2001). Both the objective registered performance of the subjects using the tested devices and the subject's reaction on the devices showed only minor differences among the subjects. Therefore, the number of subjects in laboratory tests could be reduced without reducing the possibilities to register differences in performances of the devices using different anti-slip devices. Four of the subjects from Test 0, still half of them female, participated in the Laboratory Tests A, B, C and D using the methods developed in Test 0. After completing these tests, it was found out that a device rejected in the tests were approved in the *Conformité Européenne* (CE = in accordance with appropriate EU-directive) approval process. Therefore it was interested to verify and develop the method, and to compare it to the test procedure used by the Notified body (an organization that has been notified by the European Commission to perform tests according to appropriate EU-directive) that performed the CE-approval process. Another objective of the studies at this stage was to find out if there were any differences in performance of the devices between subjects of different ages. The benchmarking of the test procedure was made with respect to friction, gender and age variation in group differences. Therefore Test E was conducted with 107 subjects, 57% female, with adults from a wide range of age, aged 22 to 80 years old to make sure the test methods were valid and reliable and the results were compared with results from FIOH. For the Intervention study, Test F, adults from all ages, aged 27-67 years old were again included. In this test, 60% of the subjects were women.

The tests were done using anti-slip devices available in Sweden: The devices were either available in the marketplace or prototypes were available directly from the manufacturer. The tested anti-slip devices were manufactured in different countries, such as Sweden, Norway, Finland, Germany, the United Kingdom, Italy, Austria, Canada and the United States.

Materials and procedures

There are different types of anti-slip devices covering different parts of the shoe (See Figure 3). An anti-slip device used only under the forefoot is referred to as a Foot-blade device (F). A device attached under the heel is referred to as a Heel device (H). A device covering more than half of the shoe or located both underneath the heel and the forefoot is referred to as a Whole-Foot device (WF). A device with several parts that can be combined for different uses also has been tested in a combination covering both the heel and the forefoot and is referred to as F/WF/H device.

Anti-slip devices are primarily used when walking outdoors. They can either be removable or firmly attached to the shoe. Those mounted on the shoe can either be always activated or be activated/deactivated by the user.

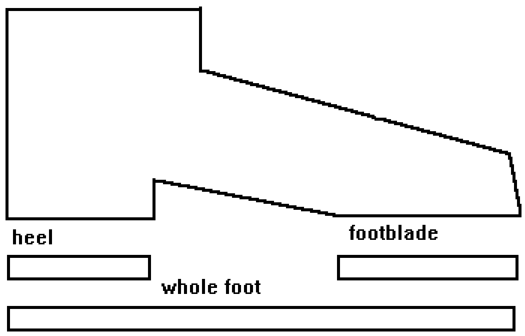

Figure 3. *Principal types of anti-slip devices.*

Besides actually being used the anti-slip devices has to be activated/put on and deactivated/taken before and after a walk. The anti-slip devices have to be stored or carried along to be available for use. Eventually they also have to be cleaned from snow, sand, and so on. All these phases are of importance for the design of an anti-slip design and of importance when a consumer is choosing an anti-slip device for their own use.

Five different surfaces were used for the tests: snow on ice, sand on ice, gravel on ice, salt on ice and pure ice (See Figure 4) (Gard and Lundborg, 2000; Gard and Lundborg, 2001). The walking area was designed to represent the conditions in the traffic environment with different surfaces and a slight sideways inclination (<2.5%). The different surfaces were chosen to simulate the variation in winter maintenance measures on walkways. Especially the sequence snow on ice before pure ice was chosen to see if snow would get attached to the anti-slip device and reduce the anti-slip effect on the following track, pure ice.

A walking cycle was chosen to simulate general pedestrian behaviour that also accounts for areas close to, and on, pedestrian crosswalks. Studies from Japan indicate that pedestrian crosswalks might be more exposed for injuries from slip and fall accidents during wintertime. Especially in steep transition from sidewalks to ice-covered pedestrian crosswalks as well as in black-ice-covered pedestrian crosswalks (Shintani et al, 2002 and Shintani et al, 2003a).

The walking cycle for each walking area was divided into six parts to simulate a stressed walking situation on, or close to, a crosswalk:
1. Walk "normally" across the whole area (walking on a sidewalk or on a crosswalk without stress)
2. Turn around (changing direction when approaching a crosswalk)
3. Walk rapidly 4-5 steps (starting to walk on a crosswalk with approaching vehicles)
4. Stop (stopping for approaching vehicles)
5. Walk backwards 4-5 steps (to avoid to be hit by approaching vehicles)
6. Walk rapidly across the whole area (stressed by approaching vehicles)

All tests were performed from -2^{o}C to -7^{o}C, which is slightly lower temperatures than those used by Gao (2001), who compared subjective slipperiness and COF using winter shoes. Therefore, COF in the tests is expected to be higher than those presented by Gao (2001).

Below -10^{o}C, the COF on ice typically increase rapidly because there are no longer free water molecules acting as a lubricant.

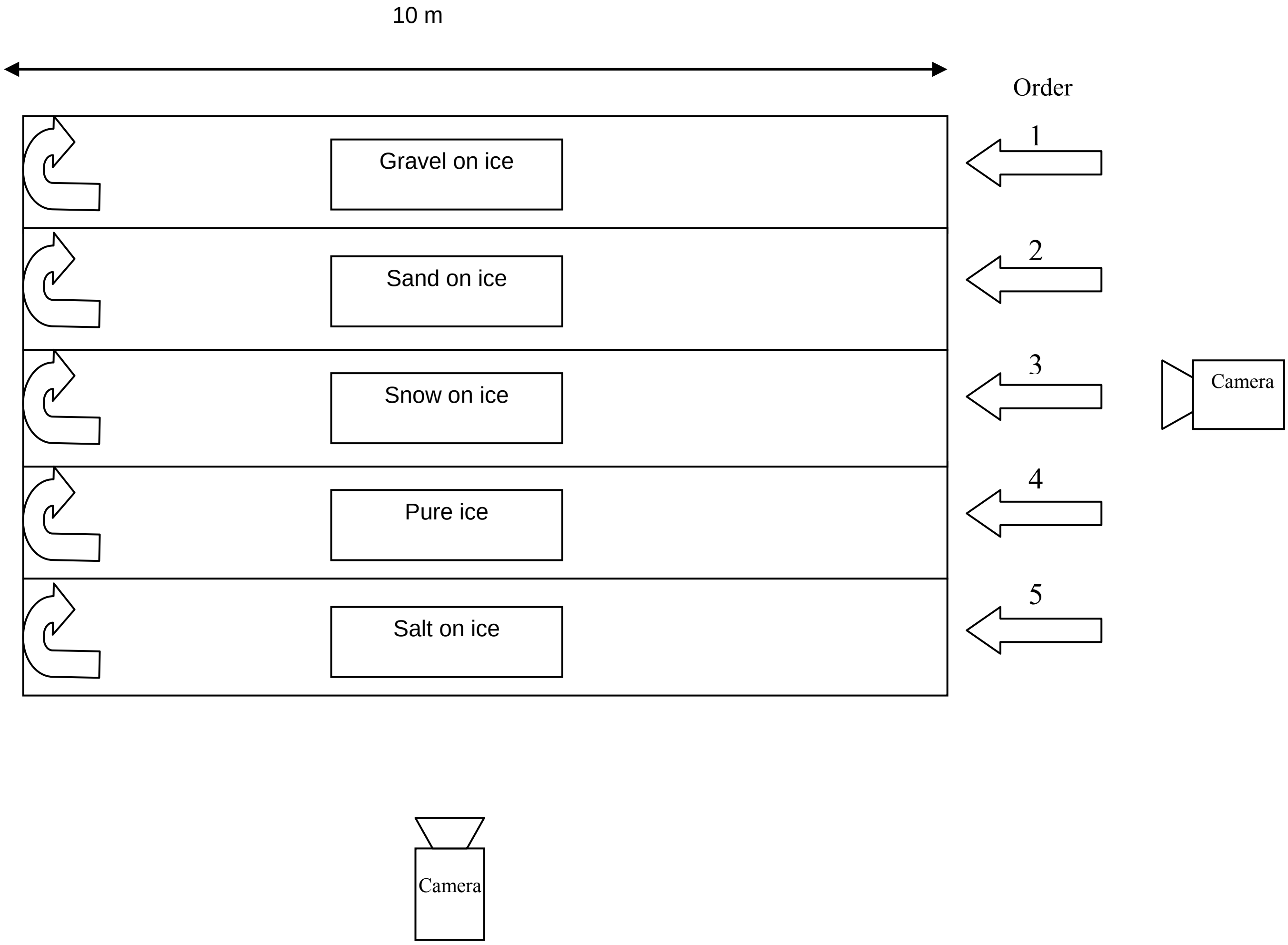

Figure 4. *The test tracks used.*

A test methodology was developed. All subjects were videotaped from both the side and front/backside. Movement analyses were made from video recordings. The analysed movements and the rating scales are presented in Gard and Lundborg, 2000 and Gard and Lundborg, 2001. Subjective rating scales were developed to assess walking safety and walking balance. Questionnaires were used to register the ratings and other data. No specific safety precautions were taken during the experiments. In Test 0 and A-E the subjects volunteered to participate from a random sample, were informed about the risk, they primarily used their ordinary winter shoes and they were all experienced winter pedestrians. Helmets were offered but no subject elected to use them. Slips occurred several times and still no subjects choose to wear helmet.

A law has been in force since 1 January 2004 which deals with vetting the ethics of research that involves humans in Sweden. When two of the departments at Luleå University of Technology in Sweden wanted to support outdoor activities among the employees such as walking/running outdoor during wintertime and therefore supplying them with anti-slip devices an opportunity to evaluate the use of anti-slip devices occurred without needing the ethical approval. In the field study, Test F, daily diaries and questionnaires were used to register the background of the subject, exposure, occurrence of slips/falls, description of the slip/fall that occurred and experiences of the use of anti-slip devices. The results were analysed by using SPSS 15.0.1. The subjects were chosen among employees from in total five departments at LTU. The subjects were divided into three groups: an Intervention Group (N=25), a Control Group (N=25), with similar distribution of gender and age, and a Comparison Group (N=17). The Intervention Group and the Control Group were invited to participate in a health promotion project and were invited to separate information meetings to discuss problems and benefits of walking during the wintertime and the importance of the assessment presented here. The Comparison Group was just informed, in writing, about the importance of their participating in a travel survey. No one where prohibited to use safety equipment or anti-slip devices of their own. The subjects in the different groups showed similar distribution with respect to gender (60% female) and age (27 – 67 years).

RESULTS

Development of test methods

The rating scales for tested reliability for perceived walking safety was 86% and for walking balance 88%. The four rating scales for walking movements were also tested for inter-rater reliability by two experienced physical therapists. The dimensions evaluated were:

- Walking posture and movements including normal muscle function in the hip and knee. The two therapists had a rating agreement of 85%
- Walking posture and movements in the rest of the body (head, shoulders, and arms), 80% agreement
- Heel strike, 86% agreement
- Toe off, 85% agreement.

It is important to have as high inter-rater reliability as possible. According to Nunnally (1978) a good inter-rater reliability has to be over 70%, which obviously was met in these studies.

The results from the rating scales for perceived walking safety and walking balance were presented as number of subjects with no, bad, fairly good, or good perception for each of the devices on each of the different surfaces.

The results from Test A and Test B, showed that the rating scales describing perceived safety and balance as well as the observation methods for observing movements were reliable and could be used to describe walking safety, walking balance and walking movements when walking with anti-slip devices on slippery surfaces. The measures to choose an anti-slip device for personal use and to list the perceived advantages and disadvantages could also be used in the test situation. These practical measures are important, since they can show how to increase the usability of the anti-slip devices. The subjective choice of an anti-slip device for personal use where each subject made a priority list according to safety, balance and appearance is also a relevant measure in studies from this field, as the subjects' own priorities often direct their everyday behaviour. Evaluating the perceived advantages and disadvantages of each anti-slip device after walking with each of them was also recommended for further use. The comparison of the subjects' highest priorities for their personal use is also a valuable practical measure in product development of anti-slip devices (Gard and Lundborg, 2000).

The experience of the surfaces used in the tests indicates that surfaces covered with gravel and sand can be excluded as the differences between the performances of the anti slip devices could not be observed as the friction of both the surfaces were too high, i.e. sufficient (Berggård et al, 2010).

The experiences from Test A-D show that several of the 33 tested devices are non-functional devices. Still, one device has later been CE-approved. Therefore there is a need for a standardized test to exclude not properly functioning anti-slip devices. Several other tested devices that did not succeed so well in the tests have not been CE-approved and are therefore not available on the market.

Since 1997 (Grönqvist & Mäkinen, 1997), there have been suggestions for the establishment of a European standard for special footwear and attachments containing spikes or studs for occupational use. This is not sufficient. A standard should also be established for special footwear and attachments containing spikes or studs for private use because most of the injuries occur outside working hours. Comparative tests were made to evaluate which methods should be used in such a standard. The measurement of available friction is not sufficient to have a safe use. The actual human behaviour is also of importance. Therefore the standard should have a human-centred approach (Berggård et al, submitted)

The results from the larger Laboratory test, Test E, on the use of anti-slip devices among a larger group were presented and the methods used were evaluated in Test E (Gard and Berggård, 2006). Because the previous Laboratory tests (O, A-D) were conducted with a relatively small number of elderly subjects, Test E were made to establish a better knowledge of whether there were any differences among different age groups or gender on the use of the best of three different types of anti-slip devices previously identified. A total of 107 subjects participated, aged 22 to 80. The three different designs of anti-slip devices, i.e. heel device, foot blade device and whole foot device, were evaluated. Time to walk with each device was also included in Test E. The results are presented as frequencies of the subjects' different perceptions and observers' different observations. For all subjects in Test E, both the objective and subjective methods were useful for comparing the properties of the anti-slip devices, and also show differences between the users, i.e differences based on gender and age.

Most of the subjective and objective methods used in this study were practical, functional and user-friendly, and could be used as part of a European standard, but video recordings of the walking cycle should probably not be included as a part of the testing for a CE-type approval process due to its high costs. The analysis, conducted by an experienced physical therapist and based on the video recordings, did not recognise as large differences in walking ability as the subject's reports of perceived balance and safety. The reported perceived balance and safety therefore seems to be a more sensitive instrument to register differences in properties of different anti-slip devices.

The movement analysis in its present form could therefore probably be excluded as one of the used methods. The experiences obtained from other research projects using similar objective method, movement analysis, should be taken advantage of though, so that, e.g., new testing methods giving the same results could be developed to conduct analyses of similarities and differences in the use of anti-slip devices on different surfaces. The focus should be on the feet during the walking cycle, particularly on heel strike and toe off, as they are the most relevant parts to study.

Valuable properties of anti-slip devices

The above mentioned methods were used to identify valuable properties of anti-slip devices, and the results were then used in ranking anti-slip devices.

When the subjects choose equipment for their own personal usage, they typically give priority to a whole-foot device. It is therefore recommended that consumers with no prior experience choose a whole-foot device to allow a normal gait and to achieve good perceived walking safety and balance on all surfaces.

The selection of tested devices in Test E is based on earlier Tests (0 and A-D) identifying good examples of anti-slip devices in each of the design groups, heel, footblade and whole foot devices. Most subjects walked with a normal muscle function in the hip and knee when walking with or without an anti-slip device on all surfaces. The heel device was observed as the quickest to take on and the toe device as the fastest to take off (Gard and Berggård, 2006).

The results showed that walking with any anti-slip device could improve perceived walking safety on snow, ice and salt and improve perceived balance on snow and ice. When comparing gender, women more than men, perceived the heel device significantly safer to use on gravel and ice and the toe device significantly safer to use on sand, gravel, ice and salt. It took significantly longer for women compared to men to walk on gravel and sand ($p<0.05$, T-test for two independent samples). When comparing age, people older than 40 years compared to people younger than 40 perceived the heel device significantly safer ($p<0.05$, T-test for two independent samples) to use on gravel and ice and the toe device significantly safer to use on sand, gravel, ice and sand ($p<0.05$, T-test for two independent samples) (Gard and Berggård, 2006).

All three devices were perceived to have a good foothold. The heel device was perceived to fit the shoe and be stable at heel strike. The toe device was easily portable and stable on uncovered ice. The whole-foot device was comfortable to walk with and safe on snow-covered ice although it did not fit so well on most of the subjects own footwear used in the study. The heel device had the highest ranking with respect to walking safety, walking balance on uncovered ice and on snow covered ice, and choice for personal use, followed by the toe device and the whole-foot device.

However, with the heel device it was observed a change in movement pattern with a clear heel strike, but a more insecure and unbalanced toe off. Still, most subjects walked with a normal muscle function in the hip and knee as well as with normal movements in the rest of the body when walking with or without each of the anti-slip devices on all surfaces. The toe device was perceived to be stable on ice, but it did not fit all types of shoes and the spikes could be felt under the foot. The whole-foot device was perceived as good on snow, but some subjects perceived it clumsy and ugly and that it moved under the foot, thus reducing the perceived balance.

A Laboratory measurements at FIOH done in Test E shows that the heel device has the highest dynamic coefficient of friction (DCOF) followed by the foot-blade device, identical to the perceived results presented above. This can be one explanation for the results, as the heel device was considered the best in walking safety and balance in the last laboratory test.

Walking ability and safety

In the Intervention study, Test F, there was no significant difference between the groups with respect to mean daily total walking distance and mean daily total walking time. The mean daily total walking distance among the subjects in this study is similar to the average walking distance according to the Swedish National Travel Survey, that is 2-3 km (SIKA Statistics, 2007).

For the subjects using anti-slip devices, the mean daily total walking distance was longer, 4.08 km, during days using anti-slip devices, compared to people not using anti-slip devices, 2.66 km, a significant difference ($df=1$, $F=86{,}139$, $p<0.05$). There is statistical differences between younger and older subjects for both the total walking distance ($df=1$, $F= 43.277$, $p = 0.000 <0.05$) and the distance with anti-slip devices ($df=1$, $F=44.818$, $p= 0.000 <0.05$). The elderly walks longer distances and uses anti-slip devices more frequently. The access to anti-slip devices in the Intervention Group resulted in a more frequent usage of anti-slip devices. The subjects in the Intervention Group accounted for 59% of the anti-slip usage, and 80% of the trips with anti-slip devices were made by people in the Intervention Group.

It should be noted that 55 of the 64 incidents/falls occurred without anti-slip devices. Only nine incidents/falls occurred with anti-slip devices. And, six actual falls occurred when not using anti-slip devices and only one when using an anti-slip device, a heel device. There were no real differences in the frequencies of incidents or falls per walking day for those who used anti-slip devices, 0.025, and those who did not, 0.026. In other words, an increased mean daily total walking distance, caused by using anti-slip devices, did not increase the number of incidents or fall occurrences. There are no statistical differences between age groups for incidence or fall occurrences; with 33 of the incidences or falls occurring among the younger subjects (-44) compared to 31 incidences or falls among the older subjects (45-).

Users of anti-slip devices experienced 6.2 incidents per 1000 km of walking. Non-users experienced 9.8 incidents per 1000 km of walking. The incidence rate ratio is 0.63, suggesting a protective effect of the anti-slip devices. However, the difference is not statistically significant (t=1.47 in t-test based on Poisson assumption), and with the 95 % confidence interval of the incidents 6.2+/-4.1 for users and 9.8 +/- 2.6 for non-users.

The rate of falls was 0.69 per 1000 km of walking for users of anti-slip devices and 1.07 per 1000 km of walking for non-users. The rate ratio is 0.64, again suggesting a protective effect of the anti-slip devices. However, the difference is not statistically significant (t=0.46 in t-test based on Poisson assumption) and with the 95 % confidence interval of the falls 0.69+/- 0.45 for users and 1.07 +/-0.31 for non-users. It should be noted that both incidents and falls were events that did not result in personal injury.

Effects of using anti-slip devices

Eleven subjects in the intervention study filled out information about their experiences of using anti-slip devices for a longer period. All of them state that they will continue to use anti-slip devices and recommend their friends to do so also. The benefits of using anti-slip devices is larger than the disadvantage because among those using appropriate anti-slip devices, the average daily walking distance was found to be significantly longer compared with people not using anti-slip devices. This study indicates that such changes can be made without increasing the risk of slips/falls. The study also shows that if people use appropriate anti-slip devices and people are provided with information about when and where to use them the number of slips and falls will be reduced.

The Swedish Gross National Product in the year 1998 was 2,012,091 million Swedish crowns (MSEK) (SCB, 2007). The expenditure for all public physical maintenance and construction in Sweden in 1998 accounted for 1.6% of this, or 33,515 MSEK. Most of those investments were targeted to the transport sector, 24,560 MSEK (73%). These costs include both maintenance and investments in new construction and reconstruction of existing infrastructure. (Räddningsverket, 2002). In the transport sector, money is primarily spent on prevention, mainly to reduce road accidents involving cars and collisions between cars and vulnerable road users. Measures to reduce injuries from single-pedestrians accidents have traditionally been given a low priority. Means, as anti-slip devices, to contribute to the prevention of injuries caused by slipping on icy/snowy surfaces should therefore be given greater importance in the future.

In Umeå (pop. 118,544), approximately 3.5 injuries from single-pedestrian accidents per 1,000 inhabitants occurred during one winter season (Björnstig, et al, 1997). Fractures occurred in half of the accidents. And, among women >50 years of age, fractures occurred in two-thirds of the accidents. The cost was 6.2 MSEK for emergency care and sickness benefits, an average of 15,000 SEK per injured. This was approximately the same as the cost as for all other types of traffic-related injuries in the same area during the same period. Therefore, injury prevention measures for single pedestrian related injuries would, from a medical and social point of view, be as important as injury prevention measures for vehicle-related injuries (Björnstig, et al, 1997).

Our study implies a possible reduction of the fall risk by one third by using anti slip devices. Thus reducing the number of single-pedestrian accidents needing medical treatment by one third annually (or approximately 10,000 injuries) in Sweden, a significant saving in expenditures for medical treatment and healthcare is expected. Based on the above-mentioned average costs (1996 expenses corrected for the increase by 35% in healthcare costs during the period 1996 to 2003 (IHE, 2006), 10 000 * 20 000 = 200 MSEK can be saved annually in Sweden. The cost of a pair of anti-slip devices is in average approximately 200 SEK. To supply all the citizens (9 miljon) in Sweden with an anti-slip device would cost 1800 MSEK compared to the cost for all of the maintenance and construction used in the transport sector annually, 24,560 MSEK, i.e. anti-slip devices are a cost efficient measure to reduce injuries in the transport sector.

DISCUSSION AND FUTURE RESEARCH

Over a period of several years, 33 different anti-slip devices have been tested using objective and subjective evaluation methods. As previously pointed out, these tests show unsatisfactory results for one anti-slip device that were later approved according to the EU directive. This implies a need to develop European and global standards for testing special footwear and attachments containing spikes or studs for private use. Comparative tests have to be made to evaluate which methods should be used. The methods should include a number of human-centred methodologies, i.e. subjective, objective, and combined, for evaluating slipperiness. Critical moments in the natural gait on slippery surfaces, such as heel strike and toe off, should be included to make it easier to analyse what type of anti-slip device (heel, foot blade or whole foot device) that should be recommended for different surfaces.

The tracks and the walking sequences used in the tests are based on the idea of where and in what traffic situation the accidents might occur and where it is of importance to be able to walk rather quickly, for example at a pedestrian crosswalk or close to it. Future studies should be made to more precisely identify other “black spots” and to inform about where to take precautions when walking outdoors during the wintertime. Test tracks should be developed to manage different inclinations, sideways and in the walking direction to resemble different kinds of traffic environment, as described also by Shintani et al. (2002).

No specific safety precautions were taken during the experiments. This may have reduced the walking pace to a slower pace in the ‘walking rapidly phase’, compared to if safe precautions had been arranged. Further studies should be made to be able to draw conclusions concerning the importance of safety precautions, such as the influence of using/not using helmets or other safety equipment. Walking speed of different age groups on different surfaces should also be considered, as pedestrians are not a homogenous group when using pedestrian crossing generally (Knoblauch, 1996; Fitzpatrick et al, 2006; Montufar, 2007; Coffin and Morrall, 1995; Langlois et al, 1997). Walking speed and general attention also differs when performing other tasks, such as walking and talking on a cell phone (Hurt and Kram, 2006). Walking and performing other tasks should therefore also be considered.

The proposed method include measuring the subjects' attitudes to each anti-slip device and the devices different characteristics regarding their handling and the usage of the devices both when attached/in use and when it is just carried along or stored away, such as attitudes towards design, ease of carrying along, etc. (Berggård, 2008). The ease of use, unhindered mobility of the foot, weight of the device, compatibility with other leg protectors and safety footwear should also be assessed.

The coefficient of kinetic friction should be measured for anti-slip devices. The devices should be described according to the subjects' perception of walking safety, walking balance, and the test subject's personal reasons for choosing an anti-slip device for personal use

When walking on slippery surfaces in general, an adopted gait is used, the step length is decreased, and the swing of the leg is restricted. The rollover phase is excluded and replaced by a flat approach by the foot to the ground and a flat lift of the foot from the ground. The heel device supports a natural heel strike, the foot-blade device supports a natural toe off, and the whole-foot device supports a natural gait with heel strike, rollover and toe off. The user adopts the gait to the specific benefit from a specific anti-slip device. Gender differences concerning the foot-blade device might originate from the experiences of most women who walk in high-heel shoes, thus using the foot blade more for safe walking.

Principally, there is a need for better and handier whole foot devices that permit a normal gait. The device should be flexible and lightweight. Devices that are too stiff give an unnatural gait with a flat approach of the shoe to the ground. No normal heel strike or toe off is obtained if the device is too stiff. However, users sometimes seem to consider other aspects. Mainly, they prefer devices that are easy to carry along and easy to put on and take off. If the anti-slip functionality is built into the shoe, further development should be made to make it easier to activate and de-activate the function. Built in activated/deactivated devices into the shoe should perhaps be temperature sensor controlled or remote controlled.

The Intervention study indicates a reduction in slip and fall rate by using anti-slip devices and an increased daily walking length on snowy and icy surfaces thereby increasing the physical strength and health. The subjects' experiences in using anti-slip devices will continue to grow and so will the number of people who recommend others to try such devices. Therefore, further studies on the use of, and the effects of using, anti-slip devices are recommended. This will enable us to compare the reduction of risk from providing and advocating the use of anti-slip devices with other risk-reduction measures.

The non-vehicle related traffic data of today is not sufficient to calculate the risk regarding time of day, time of year, type of road surface, etc. There is obviously a need for a standardised procedure to register the exposure for in this case pedestrian to be able to compare the risk of single-pedestrian accidents compared to vehicle related accidents. The exposure as a pedestrian has to be recorded, no matter if it is a part of a trip chain (with other modes of transport) or a specific pedestrian trip, and be compared with for instance actual self reported, observed, or health care system based injury data.

Anti-slip devices are a cost efficient measure to reduce injuries in the transport sector. The effect including costs of anti-slip devices should be compared to costs and effects of other traffic safety measures in the transport sector.

CONCLUSIONS

This study shows that it is possible to record the performance of anti-slip devices for pedestrian in laboratory studies by using the methods presented here. The developed methods together with objective measurements made by FIOH can be the bases for establishing a standard for testing anti-slip devices as personal protective equipment for leisure purposes. According to the intervention study on the effects of using anti-slip devices on icy/snowy surfaces exposure can increase without increasing risk of slipping/falling. The result shows an increased walking distance for anti-slip users and a reduction in slipping, and falling, when using anti-slip devices. Anti-slip devices are recommended to be used for preventing slipping and falling on icy and snowy surfaces during the wintertime.

The experimental setup with the walking cycle and five slippery surfaces is a realistic situation, and the slippery surfaces resemble identified dangerous pedestrian areas, but the surfaces used can be reduced to snow covered ice, pure ice and salt on ice. The subjective methods used measuring a subject's perception of walking safety and walking balance seem to be appropriate and are suggested to be included in a standard.

For a standard to test anti-slip devices, the following methods are recommended to be included:

- Rating scales for perceived safety and balance
- Walking time/step length/walking cycle duration
- List of subjective priorities for own use
- List of perceived advantages and disadvantages
- Measured coefficient of friction
- Tensile strength of fastening parts and spikes/studs.

A heel device was selected as the best device in the first laboratory test. In the following Laboratory tests, a whole-foot device was regarded as the best to use. But in the last Laboratory test, the whole-foot device did not fit properly to some of the subjects' shoes, thus reducing the anti-slip support and a heel device was considered to be the best device. Using a heel device may imply a more focused and gentle heel strike and thus increase the heel device/surface area during heel touch-down, further explaining why the heel device was selected as the best in walking safety and balance in the last laboratory test. Still a whole foot device properly attached to the shoe is considered to be the best device. A whole-foot device should be supporting a normal gait with proper heel strike, gentle roll over and a safe toe off.

New anti-slip devices still needs to be developed and designed with the studs/pins located closer to the perimeter of the device to ensure a good grip independent of which part of the device that is in contact with the surface and independent of what type of device it is.

The average daily total walking distance in this study is similar to the walking distance found in the national travel survey data. Among those using appropriate anti-slip devices, the average daily walking distance was found to be longer compared to people not using anti-slip devices. The anti-slip users increased their exposure without increasing the risk of slips/falls.

The risk of an incident/fall and an actual fall is indicated to be reduced by using anti-slip devices, 0.67 and 0.64 respectively. Anti-slip devices prevent people from falling. The use of anti-slip devise can therefore be used to increase the exposure without increasing the risk of having incidents/falls and experiencing actual falls.

The users of anti-slip devices states that they will continue to wear them and they will also recommend others to do so. By reducing slip and fall accidents during the wintertime, the single-pedestrian accidents can be reduced thus improving the safety in the traffic environment for pedestrians.

This study conclusively shows that by using appropriate anti-slip devices, information about when and where to use them—which depends on their design— anti-slip devices reduce the number of slips and falls that people have. This leads to a reduction of the costs for the society for injuries of falling pedestrians.

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