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Model-based economic evaluation of ice cleat distribution programmes for the prevention of outdoor falls among adults from a Swedish societal perspective

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ABSTRACT

Background Slipping on snow or ice poses a significant health risk among older adults in Sweden. To combat this problem, about 80 Swedish municipalities have distributed ice cleats to older citizens (65+ years old) over the last decade. This paper details a cost–benefit analysis of such programmes.

Materials and methods We developed a decision-analytical model to estimate the costs and benefits of ice cleat programmes in Swedish municipalities compared with a business-as-usual scenario. The modelled benefits of the programme were based on effect estimates from previous research, data from population and healthcare registers and a survey of attitudes to and actual ice cleat use. The modelled costs of the programme were based on resource use data collected from 34 municipalities with existing ice cleat programmes. We assessed heterogeneity in the potential impact and benefit-to-cost ratios across all Swedish municipalities as a function of the average number of days with snow cover per year. Uncertainty in the cost–benefit results was assessed using deterministic and probabilistic sensitivity analyses.

Results The average benefit-to-cost ratio was 87, ranging from about 40 in low-risk municipalities to 140 in high-risk municipalities, implying that the potential benefits of ice cleat programmes greatly outweigh their costs. Probabilistic and deterministic sensitivity analyses support the robustness of this conclusion to parameter uncertainty and large changes in assumptions about the magnitude of the impact on ice cleat use and injuries.

Conclusion The benefits of distributing ice cleats to older adults appear to outweigh the costs from a Swedish societal perspective.

INTRODUCTION

Pedestrian falls are increasingly being recognised as an important contributor to the burden of transport-related injuries among older adults.[1–3] The problem is particularly prominent in colder regions,[4 5] where many outdoor falls are caused by icy conditions.[6 7] As a low-cost complement to conventional strategies for combatting ice-related injuries during the winter season (eg, snow removal and road salting), about 80 Swedish municipalities have implemented programmes to distribute ice cleats to their older residents at some point in recent years.[8] Ice cleats can reduce the risk of ice-related falls,[9–12] and programmes that distribute ice cleats to older adults have the potential to reduce injury rates at the population level, according to a study from Gothenburg (located in the south-west of Sweden).[13] Despite this, there have been no comprehensive economic evaluations of these programmes covering all Swedish municipalities. While empirical data from Gothenburg suggest that the benefits may outweigh the costs,[13] the impact of these programmes may vary depending on factors related to local climate conditions, such as current ice cleat use and the local risk of snow-related and ice-related fall injuries. This knowledge gap hampers the possibility for informed decisions about implementing ice cleat distribution programmes elsewhere.

Model-based economic evaluations can help bridge the gap between available empirical evidence and local circumstances that affect the potential impact of an intervention.[14] In this study, we develop a decision-analytical model to estimate the impact of ice cleat distribution programmes depending on local climate conditions and apply the model to conduct a cost–benefit analysis of ice cleat programmes in the context of all Swedish municipalities.

MATERIALS AND METHODS

Setting, location and target population

Swedish municipalities are local, self-governing authorities funded by municipal-level income taxes. They are responsible for providing several essential public services at the local level, including local traffic safety interventions. There are 290 municipalities in Sweden, with population sizes varying from about 2000 to 975 000 according to population data from Statistics Sweden. In 2019, we sent out an electronic survey to all Swedish municipalities to collect data on ice cleat programmes. Out of the 228 responses we received, 78 reported having distributed ice cleats at some point during the last decade (four before 2012 and the rest after). Most provided ice cleats (free of charge) to any citizen above the age of 65 years old. We therefore focus on this population in our study.

We also collected data on the number of purchased and distributed ice cleats and resource use (ie, costs) associated with existing programmes. The distribution data show that about 90% of all purchased ice cleats were distributed. Not all

Table 1 Model parameters, probability distributions and data sources for the decision-analytical model for economic evaluation of municipal ice cleat distribution programmes

Parameter	Average (range, if applicable)	SE	Distribution (probabilistic sensitivity analysis)	Data source
Annual number of snow-related or ice-related fall injuries at baseline as a function of population size and climate (y_j)	21.6 (2.7, 472.6)	Municipality-specific SE from regression prediction	Lognormal	Municipality-specific and age-specific data from National Patient Register[21]. Population data from Statistics Sweden[30]. Annual number of snow days from the Swedish Meteorological and Hydrological Institute*
Initial change in ice cleat use as a function of climate (θ_j)	0.25 (0.09, 0.35)	Municipality-specific SE from regression prediction	Logit-normal	National survey (random sample, n=4608 aged 65+) conducted in 2007 by the Swedish Civil Contingencies Agency*
Compliance over time, multiplicative scaling factor (ω_t)	$\{\omega_1, \cdot \{\cdot \omega_5\} = \{1, 0.75, 0.50, 0.25, 0\}$	Not available	None	Calibrated* simulation model to results from quasi-experimental evaluation in Gothenburg[13]
Effect of ice cleat use (RR), log scale	−0.799	0.333	Lognormal	Randomised controlled trial[12], RR=0.45 (95% CI: 0.23 to 0.85)†
Total programme cost per purchased ice cleat pair in 2018 Euros (c), log scale	1.998	0.100	Lognormal	Electronic survey sent to all Swedish municipalities (n=34 responses with cost data)*
Benefit per averted injury in 2018 Euros	329 783	Not available	None	Swedish Transport Administration[17]

*Additional information on data and estimation is provided in the online supplemental file.
†RR for falls (with or without an injurious outcome). Estimate for injurious falls was 0.1 (95% CI: 0.02 to 0.53) but was only based on a total of 11 events (one in the treatment group and 10 in the control group). Our preferred estimate (for falls) is supported by more data and is more conservative.
RR, relative risk.

municipalities purchased one pair per citizen; in terms of population coverage, the distribution rates imply that the programmes reached roughly 40% of the targeted age group in the average municipality.

Study design

We developed a decision-analytical model to estimate the costs and benefits of implementing an ice cleat distribution programme in a specific municipality j compared with a business-as-usual scenario. The model synthesises previous research with estimates presented in this paper to perform a population impact analysis.[15] The impact analysis provides a way to estimate the potential effect of increasing ice cleat use in a population with varying input parameters that depend on local climate conditions. Table 1 provides an overview of the base-case inputs for the model and data sources used in the present investigation. The next section provides an overview of the decision-analytical model and our empirical analyses. The online supplemental file provides additional details on the data sources and estimation strategies. Analyses were performed in R, V.4.0.2.[16]

Human subjects statement

This study used anonymised, non-sensitive data and aggregate health data from secondary sources. No human subjects were directly involved.

Decision-analytical model

We used the following model to estimate the net present value (NPV) of an ice cleat distribution programme in municipality j over the period $t = 1, 2, ..., T$:

$$NPV_j = \left\{ \sum_{t=1}^{T} \frac{1}{(1+r)^t} \left[b \left(y_{jt} \left(\frac{\omega_t \theta_j (1/RR-1)}{1+\omega_t \theta_j (1/RR-1)} \right) \right) \right] \right\} - cN_j, \quad (1)$$

where t denotes time in years from baseline and r is the discount rate for future benefits (we used 3.5% per year as recommended by the Swedish Transport Administration[17]). The first term in Equation (1) measures the total monetary benefit of the programme. Several parameters determine the benefit of the programme, including the assumed monetary benefit per averted injury, denoted by b, and the assumed impact of the programme on the number of snow-related and ice-related fall injuries at year t, which is given by

$$y_{jt} \left(\frac{\omega_t \theta_j (1/RR-1)}{1+\omega_t \theta_j (1/RR-1)} \right) \quad (2)$$

Equation (2) can be used to estimate the impact of reducing the prevalence of a risk factor in a population.[18] In our case, the risk factor is the lack of ice cleat use during icy weather conditions. In Equation (2), y_{jt} is the annual number of older adults (65+ years old) injured due to snow-related or ice-related falls in municipality j; $1/RR$ is the multiplicative inverse of the causal risk ratio of ice cleat use on the risk of outdoor fall injuries, and the term $\omega_t\theta_j$ is the causal effect of the programme on the proportion of ice cleat users, where θ_j is the initial change and ω_t is a scaling factor used to model the longevity of the behaviour change. We used data from a randomised trial of the effects of ice cleats as an estimate of the causal effect of ice cleats (relative risk (RR)=0.45; table 1).[12]

Estimation of effects on behaviour

The most challenging aspect to estimate is the effect of ice cleat programmes on ice cleat use, as there is no direct evidence on the effects of these programmes on behaviours. We do not believe that the share of collected ice cleats (90%) would be a good proxy for behaviour *change*, because a large share of the individuals who collected a pair may already own and use ice cleats. To obtain a reasonable approximation for the initial behaviour change θ_j, we instead relied on data from a national survey conducted by the Swedish Civil Contingencies Agency in 2007 that collected data on ice cleat use and attitudes towards ice cleats (n aged above 65 years old=4608; see online supplemental file for details). The data also contained information on the respondents' municipality of residence, which enabled the matching of local climate data to each respondent. As indirectly supported by behaviour change theory,[19] we assumed that non-users (respondents who reported that they do not use ice cleats during icy conditions) with a positive attitude towards the efficacy of ice cleats ('I believe that ice cleats are important or very important for increasing my safety during slippery road conditions') would be susceptible to change when presented with the option to collect a free pair of ice cleats. On average, 25% of the respondents fit this category, which we refer to as *potential compliers*. We note that this may be seen as an upper bound for the actual share of new ice cleat users; we therefore also conducted scenario analyses with lower assumed compliance rates (see below). We used a binary indicator for potential compliers as the outcome in a logistic generalised additive model[20] to establish a model for the share of potential compliers in municipality j as a smooth function of the average number of snow days per year (provided by the Swedish Meteorological and Hydrological Institute). The model results are presented in online supplemental table S2 and figure S6.

To estimate the temporal variation in compliance (ie, the scaling factor ω_t in Equation (1)), we calibrated our model to quasi-experimental estimates from Gothenburg, which found evidence of a short-lived effect on injury rates (−45% during the first year and −10% over a 4-year period[13]; see online supplemental file for calculations). Our calculations assume that this temporal dynamic is driven by a reduction in the effect of the programme on ice cleat use over time. Specifically, we modelled a relatively short-lived effect on behaviour that decreases monotonically over time and disappears completely after 4 years (table 1). We also considered a scenario where the effect is limited to the first year only.

Estimation of baseline injury rates

We modelled the annual number of persons treated for ice-related fall injuries at inpatient or outpatient facilities (International Classification of Diseases, 10th Revision, external case code: W00) at baseline, y_{jt}, as a smooth function of local climate (average number of days with snow cover per year) and population size using a negative binomial generalised additive model.[20] We used age-specific and municipality-specific data from the Swedish National Patient Register[21] between the periods 2008 and 2017, provided to us in aggregate form (ie, a total for the entire period) by the National Board of Health and Welfare. The model results are presented in online supplemental table S1 and figure S4. To estimate year-to-year variability around the municipality-specific means in our simulations, we relied on relative variation around the mean annual number of hospitalisations due to snow-related or ice-related falls at the national level (online supplemental figure S5). Overall, 61 810 persons (aged 65+ years old) were treated for snow-related or ice-related fall during the included period (municipal average: 21.6 injuries per year; table 1). Given the low fatality risk related to snow-related or ice-related falls, we only considered the benefits from averting non-fatal injuries (only 30 deaths in the age group 65+ years old occurred between 20082017 in Sweden).

Estimation of the monetary benefit per averted injury

To convert the expected effect of the programme on injury rates into monetary terms, we relied on the estimated monetary benefit per averted pedestrian fall injury used by the Swedish Transport Administration (€329 783),[17] which is based on a combination of material costs (€3592, eg, healthcare utilisation, transportation costs and informal care by family members) and the willingness to pay (WTP) per averted injury (€326 191).[17] The WTP is intended to reflect the utility loss from the injured individual's physical and psychological suffering in monetary terms. Thus, the overall benefit estimate captures both quality-of-life gains and averted material costs to society. Their estimate was obtained by taking the product of the WTP per quality-adjusted life years (QALY) (based on a stated preference survey (n=880) related to fatal and non-fatal traffic-related injuries, conducted in Sweden[22]) and the expected QALY loss per pedestrian fall injury from a remaining life-time perspective (1.387 QALYs according to data from a sample of pedestrians injured in pedestrian falls in Sweden (mean age: 64 years; n=256)[23]) and then adding the estimated material costs per pedestrian fall injury to that estimate (based on the same study as the QALY estimates,[23] although we subtracted the estimated production loss for this study as our target population is above the retirement age in Sweden; see online supplemental file for details).

Estimation of program costs

The final term in Equation (1) determines the total cost of the programme (including administration costs), which is given by the product of the total programme cost per purchased ice cleat pair, c, and the number of purchased ice cleat pairs. To model the municipality-specific programme cost, we assumed that each municipality purchases one pair of ice cleats for each citizen aged 65+ years old (N_j in Equation (1)). To estimate the programme cost per ice cleat pair, we used data from 34 municipalities that reported cost and procurement data in our survey. The average reported programme cost was €8.73 per ice cleat pair (range: 2.35–27.37). Following Bonander and Holmberg,[13] we assumed that the majority of the programme costs occur at year one in conjunction with the procurement of ice cleats.

Economic evaluation

The evaluation assumes a societal perspective, that is, it includes costs across all societal sectors in the valuation of material costs (including healthcare utilisation, administration costs, material damage to property and informal care) and WTP per averted injury.[17] Our programme cost estimates are intended to reflect the total programme costs from a municipal perspective (including the procurement and distribution of ice cleats, administration and communication). We estimated the total NPV summed over all municipalities in Sweden and studied heterogeneity in effectiveness depending on climate conditions. The results are presented in 2018 Euros, converted from 2018 Swedish kronor (SEK) assuming the 31 December 2018 exchange rate (€0.09811 per SEK).

Sensitivity analyses

We used both deterministic and probabilistic sensitivity analyses to assess uncertainty.[24] The parameter estimates, SEs and assumed distributions are presented in table 1.

In the probabilistic sensitivity analysis, we ran 100 000 simulations per municipality and used the proportion of simulations that resulted in a positive NPV to estimate the probability that an ice cleat programme would be cost-beneficial in municipality j.

In the deterministic sensitivity analysis, we varied key parameters as described in table 2. We also considered a pessimistic scenario in which we doubled the programme costs, restricted the longevity of the effect to 1 year and halved the assumed increase in ice cleat users and the effect of ice cleats compared with the base-case scenario.

Table 2 Results from the deterministic sensitivity analysis

Scenario	Expected NPV (in million Euros)	Benefit-to-cost ratio	Pr(cost-beneficial), mean (min–max)
Base-case result (for reference)	1192.62 (1061.77, 1338.12)	87.44 (77.69, 98.31)	0.991 (0.989, 0.992)
Increase cost to highest reported cost per procured ice cleat (€27.9 per pair)	1141.55 (1012.03, 1286.41)	23.55 (20.93, 26.49)	0.988 (0.981, 0.99)
Reduce WTP per QALY gained to match healthcare sector (€50 000 per QALY)	245.25 (217.05, 276.71)	18.98 (16.85, 21.35)	0.987 (0.977, 0.989)
Reduce baseline risk by a factor of 0.59 to match warmest year between 2001 and 2019	688.77 (611.34, 774.01)	51.5 (45.72, 57.89)	0.990 (0.987, 0.991)
Reduce initial compliance rate from 25% to 5% on average	281.86 (245.93, 325.25)	21.66 (18.96, 24.91)	0.986 (0.978, 0.989)
Reduce RR of ice cleat use by half (RR=0.73)	405.86 (361.81, 453.98)	30.75 (27.44, 34.38)	0.989 (0.985, 0.991)
Reduce RR of ice cleat use by three quarters (RR=0.875)	166.5 (148.28, 186.02)	13.21 (11.82, 14.69)	0.985 (0.974, 0.988)
Limit intervention effect to first year	443.49 (391.82, 502.75)	33.51 (29.64, 37.93)	0.989 (0.985, 0.991)
Increase discount rate to 5%	1160.59 (1032.03, 1303.57)	86.09 (76.49, 96.80)	0.991 (0.989, 0.992)
Cost-minimisation analysis (ignore WTP per averted injury)	−0.65 (−1.76, 0.62)	0.95 (0.85, 1.07)	0.405 (0.004, 0.720)

The table shows the results from additional scenarios to test the sensitivity of the base-case results to deterministic variations in key assumptions and input parameters. Details and rationale for each scenario is presented in the online supplemental file to this article. The estimates in the table reflect totals or means for all Swedish municipalities averaged across 100 000 simulations, with the 2.5th and 97.5th percentiles of the simulated estimates in parentheses unless otherwise noted. The simulations are run over a 4-year period. The net present value (NPV) is given by Equation (1), which, if positive, implies that the interventions are cost-beneficial. The benefit-to-cost ratio expresses how much the estimated benefits outweigh the costs in relative terms. Pr(cost-beneficial) is the proportion of the 100 000 simulations in which the NPV is positive, which gives an overall estimate of how likely it is that an ice cleat programme would be cost-beneficial according to the model (for this parameter, the numbers in parentheses reflect the least to most certain municipal-specific estimate).
Pr, probability; QALY, quality-adjusted life years; RR, relative risk; WTP, willingness to pay.

Given the conceptual uncertainty regarding our estimates of the share of potential compliers, we also performed a breakeven analysis for each municipality to estimate the minimal required share of the target population who would need to start using ice cleats for the programme to be cost-beneficial. We obtained this number by solving for the non-negative compliance share that minimises the square of Equation (1) (ie, results in an NPV that is approximately zero) using a box-constrained optimisation algorithm implemented in the *optimx* package for R.[25]

RESULTS

In the base-case scenario, the results show a 15 percentage point increase in the number of ice cleat users over 4 years, resulting in a 15% reduction in snow-related or ice-related fall injuries over the same period. In the pessimistic scenario, the expected change in ice cleat users is only 3 percentage points, with a 1% reduction in injuries. Due to low intervention costs, the results from both the base-case and the pessimistic scenarios showed a positive expected NPV in all Swedish municipalities, with municipality-specific percentages of simulations with a positive NPV ranging from 98.9% to 99.2% in the base-case scenario and 67.5% to 96.3% in the pessimistic scenario (table 3).

The average benefit-to-cost ratio was 87.4. This number varied from approximately 40 in southern municipalities to 140 in some of the northern parts of Sweden (figure 1A), in a geographical pattern that closely follows that of snow-related or ice-related fall injury rates per person-year (figure 1B). Our data suggest that the number of potential compliers is lower in the north due to higher baseline ice cleat use in high-risk municipalities (figure 1C,D). This indicates that there is a risk of ceiling

Table 3 Results from the cost–benefit analysis under base-case and pessimistic scenarios in which ice cleat programmes are implemented in all Swedish municipalities compared with a business-as-usual scenario without ice cleat programmes

Estimate	Base-case*	Pessimistic scenario†
Incremental benefit, total (million Euros)	1192.62 (1061.77, 1338.12)	89.16 (78.05, 101.09)
Incremental cost, total (million Euros)	13.64 (13.35, 13.94)	27.28 (26.70, 27.88)
Net present value, total (million Euros)	1178.98 (1048.42, 1324.18)	61.89 (52.35, 73.21)
Benefit-to-cost ratio	87.44 (77.69, 98.31)	3.27 (2.89, 3.71)
Percentage point change in ice cleat users over 4 years, mean	15.02 (14.96, 15.09)	3.00 (2.99, 3.02)
Expected number of injuries without programmes, total	25 192 (24 436, 26 008)	25 192 (24 440, 26 009)
Expected number of injuries with programmes, total	21 441 (20 681, 22 253)	24 921 (24 176, 25 731)
Injuries averted, total	3751 (3339, 4209)	270 (240, 307)
Relative intervention effect (rate ratio)	0.85 (0.83, 0.87)	0.99 (0.99, 0.99)
Absolute intervention effect (rate difference, 100 000 person-years)	−50.96 (−45.36, −57.18)	−3.67 (−3.26, 4.17)
Pr(cost-beneficial), mean (min–max)	0.991 (0.989, 0.992)	0.915 (0.675, 0.963)

The estimates in the table reflect totals or means for all Swedish municipalities averaged across 100 000 simulations, with the 2.5th and 97.5th percentiles of the simulated estimates in parentheses unless otherwise noted. The simulations are run over a 4-year period. The incremental benefits and costs reflect differences between a scenario where all municipalities have implemented ice cleat programmes versus a business-as-usual scenario. The net present value (NPV) is given by Equation (1), which, if positive, implies that the interventions are cost-beneficial. The benefit-to-cost ratio expresses how much the estimated benefits outweigh the costs in relative terms. The remaining estimates reflect estimated effects on the average change in ice cleat users and on injury rates. Pr(cost-beneficial) is the proportion of the 100 000 simulations in which the NPV is positive, which gives an overall estimate of how likely it is that an ice cleat programme would be cost-beneficial according to the model (for this parameter, the numbers in parentheses reflect the least to most certain municipal-specific estimate).
*Scenario using the best available estimates from table 1.
†Doubled costs, increase in ice cleat use limited to the first year, halved initial compliance and halved effect of ice cleats (compared with the base-case scenario).

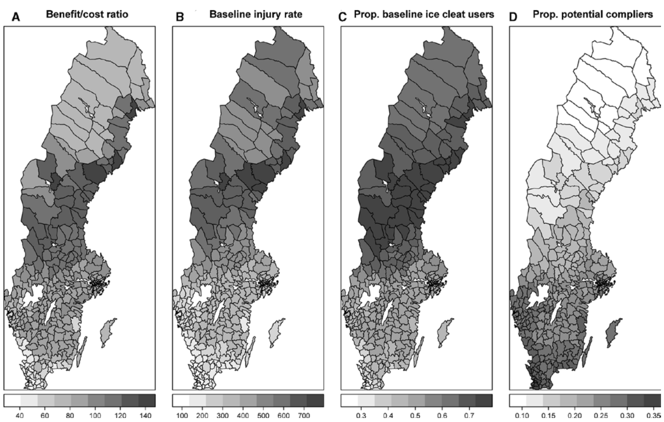

Figure 1 Maps of Sweden's 290 municipalities that illustrate the geographical variation in (A) estimated benefit-to-cost ratios from our economic simulations (base-case scenario), (B) baseline snow-related or ice-related fall injury rates per 100 000 person-years, (C) the estimated proportion of ice cleat users per municipality without ice cleat distribution programmes and (D) the estimated proportion of the population susceptible to change as a consequence of an ice cleat distribution programme (non-users with a positive attitude towards the efficacy of ice cleats).

effects concerning the magnitude of the behaviour change that could be brought about by ice cleat programmes in some areas. However, given the high injury rates in this region, our model still expects that the economic benefits of an ice cleat programme would be the largest in these municipalities.

Deterministic sensitivity analyses

We constructed a set of scenarios, each presented in table 2, to probe the sensitivity of the results to changes in key parameters (their rationale and additional details are provided in the online supplemental file). In addition to these scenarios, we also conducted a cost-minimisation analysis that ignores the valuation of health benefits (ie, the WTP per injury averted) and compares only the material costs averted to the cost of the programme. The results from these analyses are presented in table 2. Although the expected NPV varies greatly in magnitude when we modify parameters related to the expected monetary benefit per injury averted and effects of the ice cleat programmes, each cost–benefit-related scenario still indicates a positive expected NPV. The cost-minimisation analysis implies that ice cleat programmes are almost cost-neutral even if we ignore the monetary valuation of health benefits, although the total material costs are likely to increase slightly compared with a business-as-usual scenario.

Breakeven analysis

The breakeven analysis showed that at least 0.15% of the population would need to start using ice cleats for a programme to be cost-beneficial in the average municipality (range: 0.038%–0.465%), which implies that at least one person would need to start using ice cleats per approximately 670 purchased pairs for an ice cleat programme to be beneficial in expectation. In terms of injury rates, the estimated breakeven point is one injury averted per 37 800 purchased ice cleat pairs.

DISCUSSION

Pedestrian falls are underprioritised in road safety policy despite their considerable contribution to the burden of transport-related injuries.[2,3] One reason may be that decision-makers are reluctant to implement population-based programmes due to a lack of evidence on their effectiveness.[1,8] Our study implies that ice cleat distribution programmes can be an effective method to reduce ice-related falls, which is a major cause of outdoor fall injuries in the Nordic countries and regions with similar climates.[4,5,12] The results suggest that the implementation of ice cleat distribution programmes would be cost-beneficial for Swedish municipalities, which is also supported by an empirical study from Gothenburg.[13] We can now extend this conclusion to the entirety of Sweden, which supports the programmes already implemented in 78 Swedish municipalities and suggests that the remaining municipalities should consider distributing ice cleats to older adults.

A key strength of our study is the use of a model-based design grounded in high-quality data, which allowed us to thoroughly examine the potential benefits of ice cleat programmes in all Swedish municipalities under multiple realistic scenarios. That said, the study also has several noteworthy limitations. Our main concern is the estimated effect of ice cleat programmes on ice cleat use, which may be overstated. Despite this potential source of bias, our sensitivity and breakeven analyses suggest that an ice cleat distribution programme would have to be almost completely ineffective (affecting only one person per 670 targeted individuals) for it not to be cost-beneficial, which appears unlikely given previous research on ice cleats and ice cleat distribution programmes,[1,9,12,13] as well as general research on behaviour change interventions on health and safety behaviours.[26] Even so, it is important to continue monitoring and evaluating the impact of ice cleat programmes with empirical evaluation designs. However, the non-randomised nature of the implementation of these programmes presents a challenge for credible evaluation.[13] Our model, which relies partly on data from a randomised trial,[12] offers a way to assess the potential impacts of ice cleat programmes without reliance on the strong assumptions required for a causal interpretation of non-randomised data.[27]

This study only included the potential benefits of ice cleat programmes on injury outcomes. Access to ice cleats may also increase walking,[9] which suggests that ice cleat programmes may have other health benefits that are not included in our estimates.[28] Further, the economic data reflect a Swedish societal perspective. We expect that the conclusions may extend

What is already known on the subject

- Icy weather conditions are a major cause of outdoor fall injuries in colder regions.
- Ice cleats can reduce the risk of injurious falls during icy conditions.
- Distribution programmes may increase usage and reduce injury rates among older adults.

What this study adds

- This is the first comprehensive economic evaluation of ice cleat programmes.
- We model effects depending on local climate in Swedish municipalities.
- The potential benefit of distributing ice cleats to older adults outweighs the costs.

to countries with similar climates, but the context dependency of economic data may still warrant replication in other countries before drawing a conclusion on the transferability of the results.[29] Additional research is also needed to assess how these programmes can be most effectively designed to combat the potential reduction in compliance over time.

CONCLUSION

The potential benefits of distributing ice cleats free of charge to older adults appear to greatly outweigh the costs. Our results imply that the municipalities that have already implemented these programmes should continue to provide ice cleats. The remaining municipalities should consider implementing ice cleat distribution programmes.

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Competing interests None declared.

Patient consent for publication Not required.

Ethics approval The data used in this study reflect anonymised, non-sensitive information or aggregate health data from public and administrative data sources, which are exempt from the need for ethical approval according to the Swedish law of research ethics. Nonetheless, ethical approval was sought and approved by the Regional Ethics Board in Uppsala (DNR 2018/480, with addendum (DNR 2021–10338) approved by the Swedish Ethical Review Authority).

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REFERENCES

1 Schepers P, den Brinker B, Methorst R, *et al*. Pedestrian falls: a review of the literature and future research directions. *J Safety Res* 2017;62:227–34.
2 Oxley J, O'Hern S, Burtt D, *et al*. Falling while walking: a hidden contributor to pedestrian injury. *Accid Anal Prev* 2018;114:77–82.
3 Methorst R, Schepers P, Christie N, *et al*. 'Pedestrian falls' as necessary addition to the current definition of traffic crashes for improved public health policies. *J Transp Health* 2017;6:10–12.
4 Elvik R, Bjørnskau T. Risk of pedestrian falls in Oslo, Norway: relation to age, gender and walking surface condition. *J Transp Health* 2019;12:359–70.
5 Gyllencreutz L, Björnstig J, Rolfsman E, *et al*. Outdoor pedestrian fall-related injuries among Swedish senior citizens--injuries and preventive strategies. *Scand J Caring Sci* 2015;29:225–33.
6 Björnstig U, Björnstig J, Dahlgren A. Slipping on ice and snow--elderly women and young men are typical victims. *Accid Anal Prev* 1997;29:211–5.
7 Berntman M. Fotgängares olyckor och skador i trafikmiljö med fokus på fallolyckor. *Bulletin 295 / 3000* 2015;*Bulletin 295*. Available: http://lup.lub.lu.se/record/8194779 [Accessed 2 Feb 2021].
8 Holmberg R, Gustavsson J, Bonander C. Evaluation of the design and implementation of municipal ice cleat distribution programs for the prevention of a ICE-related fall injuries among older adults in Sweden. *PLoS ONE* 2021.
9 Berggård G, Johansson C. Pedestrians in wintertime-effects of using anti-slip devices. *Accid Anal Prev* 2010;42:1199–204.
10 Gard G, Berggård G. Assessment of anti-slip devices from healthy individuals in different ages walking on slippery surfaces. *Appl Ergon* 2006;37:177–86.
11 Gard G, Lundborg G. Test of Swedish anti-skid devices on five different slippery surfaces. *Accid Anal Prev* 2001;33:1–8.
12 McKiernan FE. A simple gait-stabilizing device reduces outdoor falls and nonserious injurious falls in fall-prone older people during the winter. *J Am Geriatr Soc* 2005;53:943–7.
13 Bonander C, Holmberg R. Estimating the effects of a studded footwear subsidy program on pedestrian falls among older adults in Gothenburg, Sweden. *Accid Anal Prev* 2019;132:105282.
14 Siebert U. When should decision-analytic modeling be used in the economic evaluation of health care? *The European Journal of Health Economics* 2003;4:143–50.
15 Verma A, Torun P, Harris E, *et al*. Population impact analysis: a framework for assessing the population impact of a risk or intervention. *J Public Health* 2012;34:83–9.
16 R Core Team. *R: a language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing, 2020. https://www.R-project.org/
17 The Swedish Transport Administration. Analysmetod och samhällsekonomiska kalkylvärden för transportsektorn, 2020. Available: https://www.trafikverket.se/contentassets/4b1c1005597d47bda386d81dd3444b24/asek-7-hela-rapporten_210129.pdf [Accessed 18 Feb 2021].
18 Heller RF, Buchan I, Edwards R, *et al*. Communicating risks at the population level: application of population impact numbers. *BMJ* 2003;327:1162–5.
19 Gielen AC, Sleet D. Application of behavior-change theories and methods to injury prevention. *Epidemiol Rev* 2003;25:65–76.
20 Wood SN. Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. *Journal of the Royal Statistical Society Series B* 2011;73:3–36.
21 Ludvigsson JF, Andersson E, Ekbom A, *et al*. External review and validation of the Swedish national inpatient register. *BMC Public Health* 2011;11:450.
22 Olofsson S, Persson U, Hultkrantz L. *Betalningsviljan för att minska risken för icke-dödliga och dödliga skador I samband Med vägtrafikolyckor – en studie Med kedje-ansats*. Lund: Lund University, 2016. https://ihe.se/publicering/betalningsviljan-att-minska-risken-icke-dodliga-och-dodliga-skador-samband-med-vagtrafikolyckor-en-studie-med-kedje-ansats/
23 Olofsson S, Gralén K, Macheridis K. *Personskadekostnader och livskvalitetsförlust till följd AV vägtrafikolyckor och fotgängarolyckor singel. Sammanfattning AV resultat*. Lund: Lund University, 2016. https://ihe.se/publicering/sammanfattning-personskadekostnader-och-livskvalitetsforlust/
24 Briggs AH, Weinstein MC, Fenwick EAL, *et al*. Model parameter estimation and uncertainty: a report of the ISPOR-SMDM Modeling Good Research Practices Task Force--6. *Value Health* 2012;15:835–42.
25 Nash JC, Varadhan R. Unifying Optimization Algorithms to Aid Software System Users: optimx for *R*. *J Stat Softw* 2011;43:1–14.
26 Anker AE, Feeley TH, McCracken B, *et al*. Measuring the effectiveness of Mass-Mediated health campaigns through meta-analysis. *J Health Commun* 2016;21:439–56.
27 Angrist JD, Pischke J-S. *Mostly Harmless Econometrics: An Empiricist's Companion*. 1st edn. Princeton: Princeton University Press, 2009.
28 Lee I-M, Buchner DM. The importance of walking to public health. *Med Sci Sports Exerc* 2008;40:S512–8.
29 Shields GE, Elvidge J. Challenges in synthesising cost-effectiveness estimates. *Syst Rev* 2020;9:289.
30 Ludvigsson JF, Almqvist C, Bonamy A-KE, *et al*. Registers of the Swedish total population and their use in medical research. *Eur J Epidemiol* 2016;31:125–36.

Supplementary Appendix

This document contains detailed descriptions of methods and materials (with discussion of noteworthy limitations associated with each parameter estimate), and supplementary tables and figures for Bonander, Holmberg, Gustavsson & Svensson *A model-based economic evaluation of ice cleat distribution programs for the prevention of outdoor falls among adults from a Swedish societal perspective*. It is intended to provide additional insight into the authors' work and the data that supports the economic analysis presented in the paper, including a transparent account of the known limitations of the study. All costs are presented in 2018 Swedish kronor (SEK) throughout the supplement.

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List of supplementary tables

1. Methods

In this section, we provide additional details about the input data and estimation of the parameters of the simulation model described in the main text. We reproduce the equation for the model here for convenience. We estimate the net present value (NPV) of an ice cleat distribution program in municipality j over the time period $t = 1,2,\ldots,T$, compared to a business-as-usual scenario, using:

$$NPV_j = \left\{\sum_{t=1}^{T} \frac{1}{(1+r)^t}\left[b\left(y_{jt}\left(\frac{\omega_t\theta_j(1/RR-1)}{1+\omega_t\theta_j(1/RR-1)}\right)\right)\right]\right\} - cN_j, \tag{1}$$

where *t* denotes time in years from baseline. The other parameters are introduced in the main text. In the upcoming subsections, we detail the data and estimation used for each.

1.1 Assumed discount rate

We used $r = 0.035$ to discount future benefits (i.e., 3.5% per year), which is the rate recommended by the Swedish Transport Administration (The Swedish Transport Administration, 2020). We also considered $r = 0.05$ in our deterministic sensitivity analysis. Costs are not discounted since they all refer to the first year of the intervention, and discounting thus refers to future benefits only.

1.2 Estimation of program costs

We sent an electronic survey to all municipalities in Sweden (n = 290) to collect data on existing ice cleat programs. Of the municipalities that reported having a previous or existing ice cleat distribution program (n = 78), 34 reported data on total program costs and the total number of ice cleats pairs purchased by the municipality. Preferably, all costs associated with the program should be identified and valued, which include the cost of procuring and distributing the ice cleats as well as the time costs for the personnel that lead and work with the ice cleat distribution program.

The obtained cost data varied in quality; some municipalities only reported a total program cost without specifying which cost items were included in their calculations (n = 14). The remaining municipalities reported which cost items they considered. Most of these municipalities reported only the procurement and distribution costs (cost of ice cleats, n = 12), while others provided high-quality data on ice cleat costs, staff costs and (when applicable) the cost of media campaigns related to the program (n = 8).

A histogram of the obtained cost data is presented in Figure S1. Overall, the average reported program cost per purchased pair of ice cleats was 89.9 SEK (SD: 56.8, range: 24.0 to 279.0). We compare the reported costs by groups based on reporting quality in Figure S2. The mean cost estimate was slightly lower in the group that only reported ice cleat costs, but there was no significant differences in means depending reporting quality according to a one-way analysis of variance (ANOVA; p = 0.35), nor in medians according to a Kruskal-Wallis test (p = 0.47). We also found no evidence of a relationship between program cost per ice cleat and program scale (as measured by the number of purchased ice cleats; Spearmans's rho = 0.1, p = 0.56), indicating that the scale of the program is not an important biasing factor in our economic model.

In our model, we make the simplifying assumption that the municipality buys one pair of ice cleats for each population member over the age of 65 years to estimate the total program cost in a specific municipality. This number is based on the total program cost for an average program and should, in addition to the costs of ice cleats, also include administration costs and the cost of media campaigns (as reported by our sample of municipalities with existing programs).

1.2.1 Uncertainty estimation

In the probabilistic sensitivity analysis, we use the mean and standard error of the logarithm of the cost per purchased ice cleat from survey data to simulate costs assuming a log-normal distribution. In the deterministic analysis, we consider a scenario where we replace the mean cost with highest reported cost (279 SEK).

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1.2.2 Strengths and limitations

Strengths:

- We use data from 34 existing programs in Sweden to estimate costs.
- There is no evidence of scaling effects on costs depending on program size.

Limitations:

- We lack insight into the exact calculations (i.e., data per cost item) used by many municipalities. However, the cost data is consistent across groups of municipality based on reporting quality.

1.3 Estimated effect of ice cleat use on injury risks

We rely on data from a randomized controlled trial (RCT) conducted on 109 older adults (age range: 65-96 years) in Wisconsin, USA (McKiernan, 2005). To our knowledge, this is the only study that provides a credible estimate of the causal effect of ice cleats on falls and fall-related injuries. The study is relatively small and the estimates, which are based on only a few events, are thus imprecise. The estimated *RR* for falls is 0.45 (95% CI: 0.23-0.85). For injurious falls, the estimated *RR* is 0.1 (95% CI: 0.02-0.53).

There are reasons to suspect that these estimates may be overly optimistic. For instance, the trial sample only includes individuals who had fallen at least once during the previous year. While it is not directly obvious that the *RR* would differ from a general population sample, one could suspect that the efficacy might be smaller in healthier groups.

In addition, the estimate for injurious falls is only based on 11 events (10 in the control group, 1 in the treatment group), and can therefore be characterized as an extreme estimate based on very little data. The *RR* for falls is based on 62 events (43 in the control group, 19 in the treatment group). While we are more interested in the effect on injurious falls, we believe that the more conservative estimate for falls may be more appropriate given the sample size it is based on. Further, ice cleats are designed to reduce the risk of injury via a reduction in fall frequency. Unless ice cleats also have an effect on injury severity, a reduced fall risk could serve as a reasonable proxy for reduced injury risk. We therefore rely on the *RR* for falls in our base case estimation, which is more conservative than relying on the estimate for injurious falls.

1.3.1 Uncertainty estimation

We assume a log-normal distribution for the *RR*, with standard errors derived from the reported confidence intervals, in our probabilistic analyses. In our deterministic sensitivity analyses, we decreased the assumed effect by half (RR = 0.73) and by three-quarters (RR = 0.875), given our concern that the effect size may be overstated for a general population of older adults.

1.3.2 Strengths and limitations

Strengths:

- We rely on estimates from an RCT, which is the gold standard for estimating the causal effects of treatments.

Limitations:

- The effect estimate comes from a single study with a small sample.
- The estimate is based on a sample of older adults from the US who had a history of falls, and may not be directly generalizable to our target population.

1.4 Estimation of the monetary benefit per injury averted

We used the most recent estimates of the monetary value of an averted pedestrian fall injury (*b* in Equation (1)) used for economic evaluations by the Swedish Transport Administration (3 380 826 SEK) (The Swedish Transport Administration, 2020), as we believe that this is the most relevant estimate for the context of our study. An English summary of their guidelines can be found here [accessed 2021-02-18]. Generally speaking, the monetary benefit per injury averted (from a societal perspective) is a combination of the reduced material costs in terms healthcare utilization, production loss (e.g., due to sick leave or death), administration costs, material damage to property, and informal care (e.g., by family or friends), in addition to the willingness to pay for an averted injury in the population (The Swedish Transport Administration, 2020). The willingness to pay is intended to reflect the utility loss from physical and psychological suffering in monetary terms.

Given that our target population is above the standard retirement age in Sweden, we subtracted costs related to production loss (34.7% of the total material costs according to (Olofsson, Gralén, et al., 2016)), which is 56 075 SEK * (1-0.347) = 36 612 SEK. This gives an adjusted monetary benefit of 3 361 363 SEK, which we used in our main analyses. This adjustment does not affect the end result to a meaningful extent, as the majority of the estimated benefits per averted injury (3 324 751 SEK, 98.3%) are related to the estimated willingness to pay for an averted pedestrian fall injury. Fatal falls are not included in this figure due to a very low fatality risk related to pedestrian falls[1].

The willingness to pay estimate is based on a stated preference survey using the so-called chained approach, which combines willingness to pay and standard gamble questions, conducted by Olofsson, Persson *et al* (2016) (n = 880). The survey was conducted on the behalf of the Swedish Transport Administration to estimate the value of QALYs lost due to fatal and non-fatal traffic-related accidents in Sweden. These estimates were then related to the average QALY loss per pedestrian fall injury, which is based on EQ-5D follow-up surveys collected from a sample of individuals injured and treated (emergency and/or inpatient care) for pedestrian falls in Sweden (n = 256, mean age: 64 years, average estimated QALY loss: 1.387) (Olofsson, Gralén, et al., 2016). The surveys were collected up to a year after the event, and extrapolated to the remaining expected life years per respondent with a

[1] According to public use data from the Swedish National Patient and Cause of Death registers (accessed 2021-02-16 via the National Board of Health and Welfare's website; www.socialstyrelsen.se), 30 people above the age of 65 years died due to a snow or ice-related fall (ICD-10 code: W00) in Sweden between 2008-2017. Meanwhile, 53 791 patients over 65 years were treated at inpatient and/or outpatient facilities due to non-fatal snow or ice-related falls, which implies a very low case-fatality rate.

discount rate of 3.5% per year as recommended by the Swedish Transport Administration (The Swedish Transport Administration, 2020).

1.4.1 Uncertainty estimation

In the main text, we present a deterministic sensitivity analysis based on an alternative (lower) willingness to pay estimate given its central role in the estimated monetary benefit per injury averted. Our choice of alternative is based on the observation that the implied willingness to pay per QALY assumed by the Swedish Transport Administration is approximately 2 400 000 SEK, which is about five times the number recommended for reimbursement decisions within the healthcare sector in Sweden (500 000 SEK) (Socialstyrelsen, 2011). Assuming this willingness to pay per QALY instead, the estimated monetary benefit per injury averted is reduced to (1.387*500 000) + (36 612) = 730 112 SEK. We used this figure in our sensitivity analysis.

1.4.2 Strengths and limitations

Strengths:

- Estimates of monetary benefits per averted injury are directly relevant to the decision-making context in this study; they are used by the Swedish Transport Agency and based on data from a Swedish samples.

Limitations:

- The QALY estimates are based on a sample that is, on average, younger than our target population. All else being equal, the extrapolation to remaining life years is therefore likely to overestimate the QALYs lost for an average person aged 65+ years. However, older people are more fragile and likely to suffer from severe injury after a fall, which speaks for a potential bias in the opposite direction as well. We also note that the age distribution of older people (65+ years) treated at inpatient and outpatient facilities for ice and snow-related fall injuries has the highest density at 65 years (Figure S3), indicating that a sample with a mean

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age of 64 years (as was used to estimate lost QALYs) may be reasonably accurate for our target population.

- Willingness-to-pay studies to identify the monetary value of the health risks are known to have potential biases, such as hypothetical bias (overstating WTP because no real transaction is made) and scope bias (difficult for respondents to assess how WTP relates to small changes in baseline risks).

1.5 Estimation of annual injury rates per municipality

The National Board of Health and Welfare supplied us with aggregate, municipality-level data on the number of patients aged 65 years or above treated for snow and ice-related injuries (International Classification of Diseases [ICD-10] external cause code: W00) as reported to the Swedish National Patient Register. For each municipality (n = 290), we received an aggregate sum of patients treated at outpatient and/or inpatient facilities over the period 2008-2017.

We obtained data on age- and period-specific population size for each municipality from Statistics Sweden (based on data from the total population register), which we used to determine the number of person-years of observation in each municipality.

Finally, the Swedish Meteorological and Hydrological Institute (SMHI) supplied us with estimates of the yearly number of days with snow cover per municipality. The values were interpolated from 338 measurement stations located around the country (collecting data on snow depth) and correspond to estimates for the regional center in each municipality (averaged over the period 2003 to 2018).

Statistical model

We modelled the total number of patients across the entire 10-year period (O_j) as a function of annual number of snow days (S_j) and person-years of observation (P_j). We used the *mgcv* package for *R* to fit a negative binomial generalized additive model with automatic knot selection for the spline terms. The model can be expressed as:

$$\ln O_j = \alpha + f(S_j) + f(\ln P_j) + \epsilon_j$$

where α is the intercept, $f(S_j)$ and $f(\ln P_j)$ are flexible spline terms and ϵ_j is the error term. The model output and estimated splines are presented in Table S2 and Figure S4, respectively. To estimate y_j for our simulation model (Equation (1)), we computed an annualized number of patients using $\hat{y}_j = \exp(\widehat{\ln O_j})/10$.

1.5.1 *Uncertainty estimation*

We used the point estimate $\widehat{\ln O_j}$ and its associated standard error (on the log scale, obtained using the *predict* function in R) to simulate the conditional mean injury rate in a given municipality depending on its age-matched population size and climate. We assumed a log-normal distribution for the conditional mean.

The number of ice and snow-related injuries can also vary heavily from year to year within the same municipality. As we do not have access to annual data for each municipality, we used the relative year-to-year variability around an average year at the national level to characterize yearly fluctuations around the municipality-specific conditional means. We restricted this analysis to inpatient data in order to gain access to a longer time series (2001-2019; publicly available data from the National Board of Health and Welfare; www.socialstyrelsen.se [accessed 2021-02-16]). The time series is presented in Figure S5. In each draw of the simulation, we drew a random number from a log-normal distribution with the same mean and standard deviation as the data in the figure. The resulting number is used as a multiplicative factor x_t to model the yearly variation around the estimated conditional mean. The estimated injury rate at time *t* and municipality *j* is then given by $\hat{y}_{jt} = x_t \hat{y}_t$.

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1.5.2 Strengths and limitations

Strengths:

- Swedish population registries contain virtually complete data on population size (Ludvigsson et al., 2016).
- The Swedish National Patient Register has complete national coverage of outpatient and inpatient facilities, and the data is considered to be of high quality (Ludvigsson et al., 2011).
- We can model local annual injury rates as a function of climate and population size.

Limitations:

- Potential coding errors (e.g., missing external cause codes) in the hospital data may lead to underestimation of the true injury rate per municipality. This could, in turn, lead to an underestimation of the absolute intervention effect in our simulations.
- Seventy-eight municipalities have already implemented ice cleat programs (74 of them after 2012), and the effects from these may be present in some municipality-years during the period. This would artificially lower the baseline rate and, because we use relative effect measures to model effects on injury rates, this could bias the overall result towards the null (i.e., underestimate the actual effect of the existing ice cleat programs). Our data do not allow us to separate the already treated municipality-years. However, we believe that the effect on the overall result is likely to be small. The most substantial part of the effect is likely limited to the first intervention year (Bonander & Holmberg, 2019), and because our data represents an aggregate over the period 2008-2017, the influence of the interventions on the period-average rate should be relatively small.

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1.6 Estimation of the share of potential compliers – initial change

Conceptually, we consider the population to consist of three different groups, only one of which will be susceptible to change. First, we have the always-takers. This group would own and (always or almost always) use ice cleats during icy road conditions even without a program, and will therefore not contribute to the effect of the program. The same is true for the never-takers, who will not change their behavior even when presented with the option to obtain a free pair of ice cleats. Finally, we have our group of interest; the potential compliers. These individuals do not currently use ice cleats, but will change their behavior because of the program.

Estimating the proportion of compliers presents some challenges, as it requires data on current usage rates in addition to some way to discern potential compliers from never-takers. A crude option would be to assume that all current non-users will start using ice cleats, but doing so would likely overestimate the effect of the program. Instead, we attempt to estimate the share of potential compliers as a subset of non-users who have a positive attitude towards the efficacy of ice cleats.

To estimate the share of potential compliers in each municipality, we obtained data from a national survey sent to random population sample aged 18-79 years by the Swedish Civil Contingencies Agency in 2007 (n = 4608 respondents aged 65-79 years; response rate: 62.1%). The general aim of the survey was to inquire about individual safety practices and attitudes towards safety measures. Among a large battery of questions, the survey asked respondents if they wear ice cleats during icy road conditions (or similar; e.g., studded footwear), as well as questions about their beliefs about the personal utility of ice cleats as a risk reduction measure. Our best theoretical prediction, based on theories of behavior change related to injury prevention (Gielen & Sleet, 2003), is that individuals who report never or almost never using ice cleats during icy road conditions ("non-users"), but state that they have a positive perception of their efficacy ("I believe that ice cleats are important or very important for increasing my safety during slippery road conditions") could be potential compliers. On the other hand, non-users who have a negative or indifferent perception of the efficacy of ice cleats would likely not change their behavior (i.e., remain non-users even with a program).

The survey data also contained information about each individual's municipality of residence. We combined the questions about ice cleat use and attitudes to obtain estimates of the proportion of compliers ("non-users with a positive attitude towards the efficacy of ice cleats") in the age group over 65 years in municipality j. Specifically, we fit a logistic generalized additive model with cubic splines (using the *mgcv* package for R (Wood, 2011)) to model potential compliance as a function of the annual number of snow days in the municipality (Table S2). This model allows us to estimate the proportion of compliers in a municipality depending on its climate. This number gives us the estimate of the initial change (θ_j in Equation (1)).

On average, our data imply that the baseline proportion of ice cleat users in the target population is 0.52 (52%). This number is close to a more recent estimate from a similar survey from 2014 (Gustavsson et al., 2020), which, unfortunately, lacks the attitude question needed to estimate the share of potential compliers. Nonetheless, the similarity in usage rates between the older and newer surveys implies that time trends in ice cleat use are not a large issue for the validity of our model.

Overall, the estimated share of compliers in the survey data is 0.25 (25%). We stress that the validity of this number is difficult to verify. According our survey of municipalities who have implemented ice cleat programs, about 40% of their target population obtained a free pair of ice cleats during the program. However, this figure likely contains both individuals who already owned a pair of ice cleats in addition to new users. In that sense, our estimate is likely to be closer to the truth.

1.6.1 Uncertainty estimation

We used the conditional mean estimate in each municipality and its associated standard error from the logistic model (on the logit scale; obtained using the *predict* function in R) to simulate the initial compliance in each municipality in the probabilistic sensitivity analysis. We assumed a normal distribution on the logit scale, and then transformed the logits to proportions.

However, the main source of uncertainty in this parameter is not sampling uncertainty; it is the conceptual uncertainty related to the ability of the survey responses to capture true compliance as well as uncertainty in the actual causal effect of ice cleat programs on ice cleat use. While we believe that our estimates are closer to the truth than simply assuming that all non-users will begin to use ice cleats as a consequence of the program, our model may still severely overestimate the true number of compliers. In our deterministic sensitivity analysis, we therefore consider an extreme scenario in which the average compliance is considerably lower (5%) than our model-based estimates (25%).

1.6.2 Strengths and limitations

Strengths:

- Our compliance estimates are based on empirical data from a Swedish sample (i.e., are contextually relevant) and have indirect support in behavior change theories related to injury prevention.
- The estimates should reflect a subpopulation of individuals who would pick up a free pair of ice cleats upon being offered, which may consist of both true compliers (new users) and previous users.
- The estimates are likely a more accurate representation of the true number of compliers than assuming that all current non-users would starting using ice cleats as a consequence of an ice cleat distribution program.
- We can model the share of potential compliers as a function of local climate.

Limitations:

- Our definition of potential compliers has uncertain concept validity with respect to true compliers (which is probably a subset of the share of estimated compliers in our data). This may lead to overestimated intervention effects.
- True compliance may also depend on factors other than climate (such as factors related to the quality of implementation or other contextual factors).

1.7 Estimation of the share of potential compliers – change over time

Quasi-experimental evidence from Gothenburg suggests that the effect of ice cleat programs may taper off after the first year (Bonander & Holmberg, 2019). The estimated impact in Gothenburg was relatively large in the first year after implementation (-45%). However, the long-term impact as smaller when averaged over a four-year period (-10%).

We include this dynamic in our model via the time-varying parameter ω_t in Equation (1). Assuming that the reduced effect can be explained by a reduction in the share of compliers over time (i.e., that ice cleat use returns to its previous levels after a certain period of time), we calibrated a monotonically decreasing *compliance curve* to data and estimates from Gothenburg. According to our model, the expected initial in Gothenburg is $\theta_j = 0.291$. Assuming a *RR* of 0.45 for the effect of ice cleats (see separate section above), a simple pattern where compliance decreases by $\theta_j * 0.75$ in the second year, $\theta_j * 0.50$ in the third year and $\theta_j * 0.25$ calibrates well to the estimated 4-year impact in Gothenburg. To err on the conservative side, we assume that the effect is gone after this point. Thus, we set ω_t to 1, 0.75, 0.5 and 0.25 for years 1,2,3 and 4 and 0 for years 5 and beyond in Equation (1).

1.7.1 Uncertainty estimation

In our deterministic sensitivity analysis, we also considered a scenario where the effect on ice cleat use is limited to the first year.

1.7.2 Strengths and limitations

Strengths:

- The compliance curve is calibrated to empirical estimates based on a difference-in-differences study of an ice cleat distribution program in Gothenburg.

Limitations:

- The true shape of the compliance curve is unknown and may vary depending on local contextual characteristics as well as factors related to the implementation of the program (e.g., degree of success in distribution, reach and communication).

2 Supplementary figures

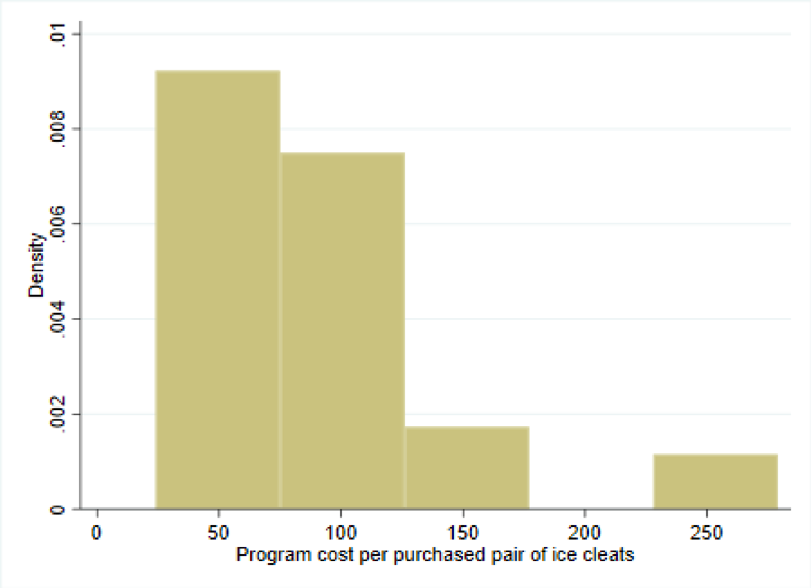

Figure S1. Distribution of reported program costs from 34 municipalities with existing or previous ice cleat distribution programs.

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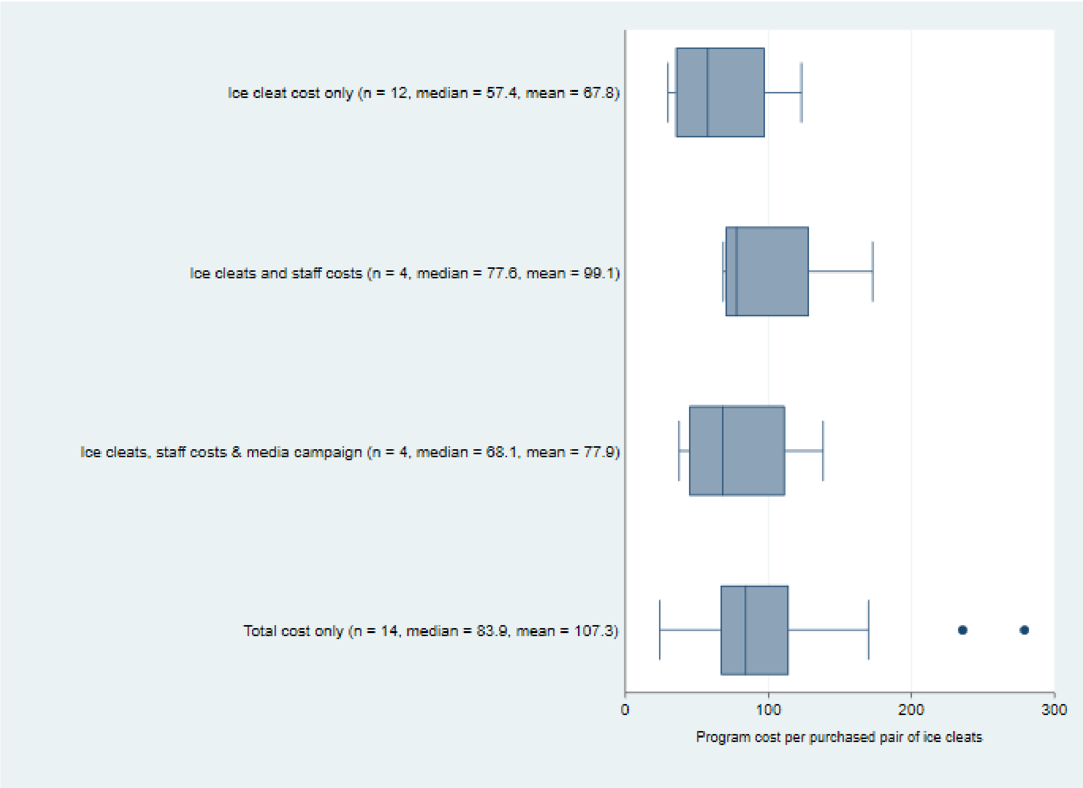

Figure S2. Distribution of reported program costs by groups based on cost item reporting quality.

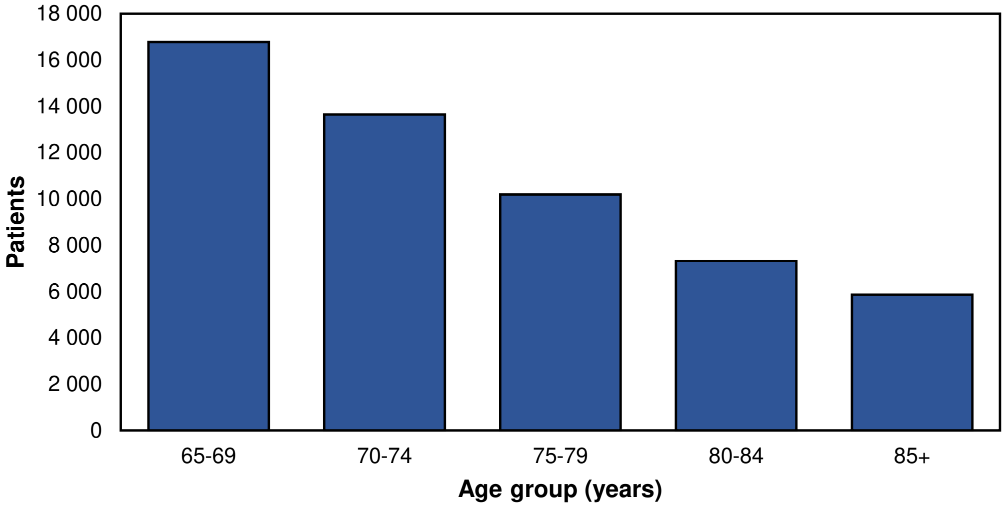

Figure S3. Number of patients (65+ years) treated at outpatient or inpatient facilities for snow or ice-related fall injuries (International Classification of Diseases [ICD-10] external cause code: W00) in Sweden by age group over the period 2008 to 2017. Data source: National Board of Health and Welfare (National Patient Register; Public data access at https://sdb.socialstyrelsen.se/if_ska/val.aspx [accessed 2021-02-16]).

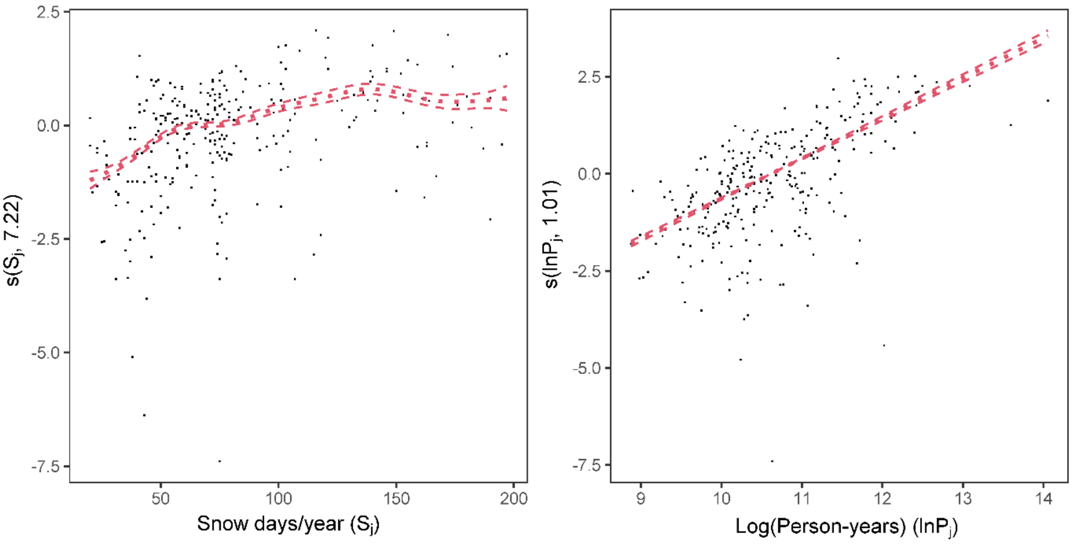

Figure S4. Effect plots for the smooth terms in the negative binomial generalized additive model predicting municipality-specific injury rates. Red lines represent point estimates and their 95% confidence intervals. Dots are residuals.

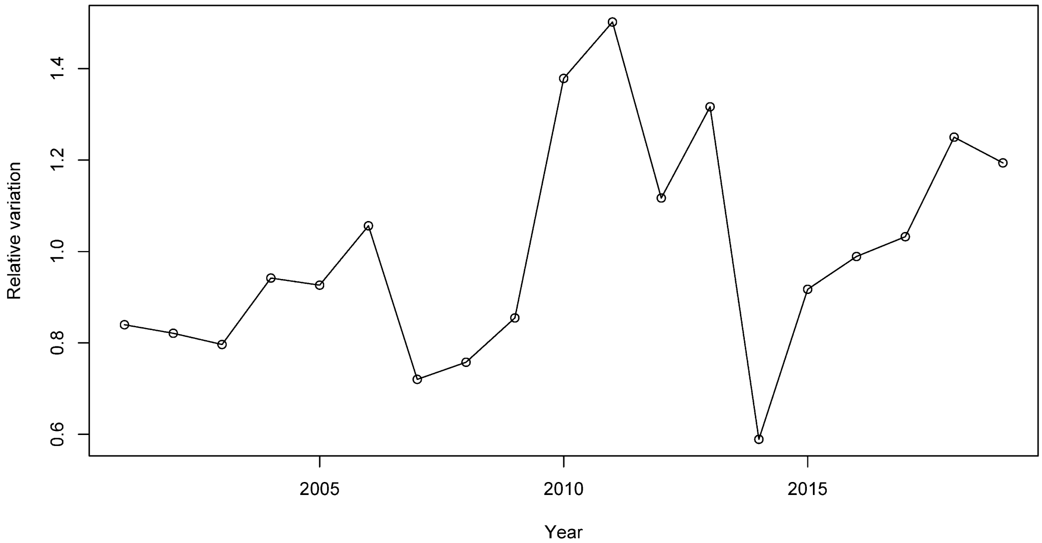

Figure S5. Year-to-year variability in patients treated at inpatient facilities for snow or ice-related fall injuries in Sweden around an average year in the period 2001 to 2019 (1 on the y-axis; multiplicative scale).

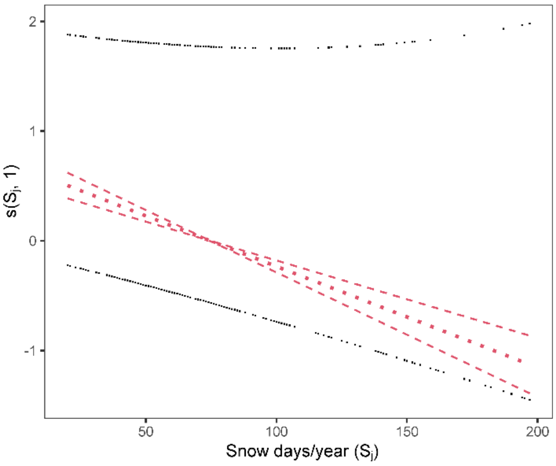

Figure S6. Effect plot for the smooth term in the logistic generalized additive model predicting the probability for compliance with ice cleat programs. Red lines represent point estimates and their 95% confidence intervals. Dots are residuals.

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3 Supplementary tables

Table S1. Model output from the negative binomial generalized additive model predicting ice and snow-related injury rates in Swedish municipalities based on annual number of snow days and the logarithm of the person-years of observation.

Parametric coefficients	**Estimate**	**Standard error**	**p-value**
α	4.89	0.02	<0.001
Smooth terms	**EDF***		**p-value**
$f(S_j)$	7.22		<0.001
$f(\ln P_j)$	1.01		<0.001
Model information	**Observations**	**Deviance explained**	**Negative binomial parameter**
	290	92.9%	14.57

*Estimated degrees of freedom for smooth terms, see Figure S4 for a visual representation.

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Table S2. Model output from the logistic generalized additive model predicting the probability for compliance with ice cleat programs among older adults (65+ years) in Sweden based on the annual number of snow days in their municipality of residence.

Parametric coefficients	**Estimate**	**Standard error**	**p-value**
α	-1.14	0.03	<0.001
Smooth terms	**EDF***		**p-value**
$f(S_j)$	1.003		<0.001
Model information	**Observations**	**Deviance explained**	
	4608	1.5%	

*Estimated degrees of freedom for smooth term, see Figure S6 for a visual representation.

4 References

Bonander, C., & Holmberg, R. (2019). Estimating the effects of a studded footwear subsidy program on pedestrian falls among older adults in Gothenburg, Sweden. *Accident Analysis & Prevention*, *132*, 105282. https://doi.org/10.1016/j.aap.2019.105282

Gielen, A. C., & Sleet, D. (2003). Application of behavior-change theories and methods to injury prevention. *Epidemiologic Reviews*, *25*, 65–76. https://doi.org/10.1093/epirev/mxg004

Gustavsson, J., Nilson, F., & Bonander, C. (2020). Individual and contextual factors associated with the use of anti-slip devices according to a Swedish national survey. *Journal of Transport & Health*, *17*, 100865. https://doi.org/10.1016/j.jth.2020.100865

Ludvigsson, J. F., Almqvist, C., Bonamy, A.-K. E., Ljung, R., Michaëlsson, K., Neovius, M., Stephansson, O., & Ye, W. (2016). Registers of the Swedish total population and their use in medical research. *European Journal of Epidemiology*, *31*(2), 125–136. https://doi.org/10.1007/s10654-016-0117-y

Ludvigsson, J. F., Andersson, E., Ekbom, A., Feychting, M., Kim, J.-L., Reuterwall, C., Heurgren, M., & Olausson, P. O. (2011). External review and validation of the Swedish national inpatient register. *BMC Public Health*, *11*, 450. https://doi.org/10.1186/1471-2458-11-450

McKiernan, F. E. (2005). A simple gait-stabilizing device reduces outdoor falls and nonserious injurious falls in fall-prone older people during the winter. *Journal of the American Geriatrics Society*, *53*(6), 943–947. https://doi.org/10.1111/j.1532-5415.2005.53302.x

Olofsson, S., Gralén, K., Macheridis, K., Welin, K.-O., Persson, U., & Hultkrantz, L. (2016). *Personskadekostnader och livskvalitetsförlust till följd av vägtrafikolyckor och fotgängarolyckor singel. Sammanfattning av resultat* (No. 6; IHE Rapport). Lund University. https://ihe.se/publicering/sammanfattning-personskadekostnader-och-livskvalitetsforlust/

Olofsson, S., Persson, U., Hultkrantz, L., & Gerdtham, U. (2016). *Betalningsviljan för att minska risken för icke-dödliga och dödliga skador i samband med vägtrafikolyckor – en studie med kedje-ansats* (No. 7; IHE Rapport). Lund University. https://ihe.se/publicering/betalningsviljan-att-minska-risken-icke-dodliga-och-dodliga-skador-samband-med-vagtrafikolyckor-en-studie-med-kedje-ansats/

Socialstyrelsen. (2011). *Nationella riktlinjer för sjukdomsförebyggande metoder 2011—Hälsoekonomiskt underlag (Bilaga)*. Socialstyrelsen.

The Swedish Transport Administration. (2020). *Analysmetod och samhällsekonomiska kalkylvärden för transportsektorn* (7.0; ASEK). https://www.trafikverket.se/contentassets/4b1c1005597d47bda386d81dd3444b24/asek-7-hela-rapporten_210129.pdf

Wood, S. N. (2011). Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. *Journal of the Royal Statistical Society. Series B (Statistical Methodology)*, *73*(1), 3–36. JSTOR.