

Projecting long-term trends in mobility limitations: impact of excess weight, smoking and physical inactivity

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Word count: 3072

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ABSTRACT

Background: Policy makers need disability projections for planning adequate services and measures for health promotion. The aim of this study is to provide projections on severe mobility limitations up to year 2044 and illustrate how the projected prevalence and the number of persons with severe mobility limitations are affected by potential changes in the modifiable risk factors, namely excess weight, physical inactivity and smoking.

Methods: We analysed the nationally representative, repeated measures Health 2000 and 2011 Surveys (BRIF8901) with 8615 and 6740 participants, respectively, aged 18 years and older. Severe mobility limitations were defined as major difficulties or unable to walk about half a kilometer. We applied a multistate model on repeated measures to account for both individual risk factors and their changes over time.

Results: The number of people with severe mobility limitations was projected to double by the year 2044 in Finland, due to the rapid ageing of the population. Eliminating half of the excess weight would reduce their number by one fifth, while reductions in the prevalence of smoking and physical inactivity would have a minor impact. Even if excess weight, smoking and physical inactivity were completely eliminated, the number of persons with severe mobility limitations is projected to increase.

Conclusions: Designing and implementing strategies to promote healthy weight are important to slow down the rapid increase in mobility limitations due to population ageing. Providing adequate health and social services for the increasing population with disabilities will nevertheless be an increasing national challenge.

Keywords: Ageing; Longitudinal studies; Obesity; Public health; Physical function.

INTRODUCTION

Understanding population-level changes in functioning is of crucial significance because the population is rapidly aging throughout the world.[1] This information is useful in making policy decisions, e.g., incentivizing health behaviors or increasing rehabilitation services. A central part of functioning is mobility, which is a prerequisite to participation in civic life as well as an important component of quality of life.[2] Restricted mobility also predicts limitations in daily activities, morbidity and falls, institutionalization, and mortality.[3,4]

Studies on long-term time trends demonstrate a decrease in mobility limitations in the 1980s and the early 1990s that levelled off and then reversed.[5,6] Recently, increases in mobility limitations among older adults have been reported in many countries,[7-11] and also in the working-aged population in the US.[7,12,13] The causes behind this increase are still debatable but increasing obesity has been suggested to have a notable influence.[14,15] The reversal of the favorable disability trends has raised a deep concern about future financing and provision of adequate services for older people (e.g. [10]).

The future development of disability will largely depend on changes in causative factors. Changes in the modifiable risk factors of mobility limitations explain a large part of the past changes in mobility.[7,14,16,17] Thus, their development is of crucial importance also in projecting future changes in mobility. The most essential modifiable risk factors affecting mobility limitations include excess weight, smoking and physical inactivity.[18-20]

Several projections indicate an increase in the disability prevalence and the number of disabled persons over the next decades.[21-25] However, the outcome has often been a quite heterogeneous set of functional limitations, and relevant modifiable risk factors have not always been included. Moreover, individual changes in risk factors over time have generally not been taken into account, nor different risk factor distributions in birth cohorts and population subgroups. Furthermore, earlier projections have neglected to account for the impact of risk factors on mortality and to consider different sources of uncertainty.

By applying multistate modelling[26] to individual-level follow-up survey data, this study aims to overcome the limitations in earlier projections and to 1) provide projections on mobility limitations up to the year 2044, and 2) illustrate how the projected prevalence of mobility limitations as well as the population size and age structure are affected by potential changes in three modifiable risk factors, namely excess weight, physical inactivity and smoking. We also incorporate the different sources of uncertainty inherent in all projections.[27,28]

METHODS

Data

The Health 2000 Survey (BRIF8901) was a nationally representative comprehensive health examination survey with assessments, interviews and questionnaires conducted in Finland in 2000–01. The two-stage stratified cluster sample consisted of 9,922 persons aged 18 years or older. The participation rate was 92%.[29]

Eleven years later all members of the Health 2000 sample, now aged 29 years or over, who had not refused further contacts, and lived in Finland, were invited to participate in the follow-up, the Health 2011 Survey resulting in a repeated measures design.[30,31] A new sample (N=1,994) of younger adults (aged 18–28 years) was also included. Altogether 10,129 persons were invited and 67% participated. The data collection is described in the Supplement.

Both surveys were approved by the Ethics Committee of the Hospital District of Helsinki and Uusimaa. The participants signed a written informed consent approving also record linkages.

Variables measured in 2000 and in 2011

Outcomes

Walking was chosen as the indicator of mobility because it enables people living in the community to accomplish many everyday activities, such as grocery shopping, reaching the bus stop or visiting neighbors [4], and therefore problems in walking contribute to disability burden. Mobility was assessed with the question “Are you able to walk about half a kilometer without resting?” with response options “with no difficulties, with minor difficulties, with major difficulties, and not at all”.[32] The two latter were combined to indicate severe mobility limitations.

Mortality follow-up on all-cause mortality obtained from Statistics Finland continued until June 30, 2012 and was individually linked with the survey data.

Predictors

BMI was based on measured height and weight. Self-reports were used if measures were missing. BMI was used as a continuous measure in the modeling. In Table 1 we report the transition probabilities using the dichotomy non-obese vs. obese ($BMI \geq 30 \text{ kg/m}^2$). Physical inactivity was based on the question “How much do you exercise and strain yourself physically in your leisure time?” with four response options describing the strenuousness of exercise. Smoking was based on the question “Do you smoke nowadays”. The response options “daily”, “occasionally” and “no” were dichotomized as daily vs. no or occasionally. Level of education was classified as low, intermediate and high. More details of the variables are presented in the Supplement (Table S3).

Statistical methods

Handling of the sampling design and missing data.

In order to handle sampling uncertainty in the survey data, we generated 36 weighted bootstrapped data sets [33] using the post-stratification weights to account for oversampling and nonresponse in the Health 2000 Survey. As the interval between measures was 11 years, we report the results based on 11-year age groups, starting at age 19, which allows us to monitor changes in the same birth cohorts or age groups over time. As walking disability is relatively rare under age 52, we report projections only in age groups aged 52 and over.

Nonresponse in the Health 2011 Survey and item nonresponse in the Health 2000 Survey were handled by multiple imputation (MI) separately in each bootstrap sample.[34] The MI was based on the chained equations, using the classification and regression trees (CART) implemented in the mice package of the R software [35] with all results based on the MI. We included all analysis variables and auxiliary variables in the imputation model, which was also applied in the creation of the projections. The CART method accounts for possible nonlinear relationships and

interactions between the variables. For young adults, the data did not include walking difficulty or the strenuousness of leisure time physical activity variables, which were multiply imputed.

Projections

The projections were generated using MI sequentially for the years 2022, 2033 and 2044 following the MI of the Health 2000 and 2011 data sets. The MI techniques allow for proper handling of the uncertainty inherent in all projections.

Individual follow-up data allowed for an estimation of the incidence rates of a multistate model.[26] The three possible states were mobile, disabled or dead, which was the absorbing state. It was also possible to move from state disabled to mobile. Our primary assumption was that risk factors and mobility limitations will change during each 11-year projection period with the same transition probabilities as between 2000 and 2011 (=null scenario), while accounting for the parameter uncertainty. The point estimate of each projection was calculated as the average of the 36 point estimates based on the imputed bootstrap data sets. The 95% prediction interval (PI) limits were calculated using the normal approximation and the standard deviation of these 36 point estimates.

We compared the null scenario with scenarios based on modifications for smoking, physical inactivity and excess weight. First, only one risk factor was changed at a time. In the ‘Smoking50%’ scenario, 50% of daily smokers were randomly chosen and moved to the non-smoker category, and this random assignment was conducted separately in each bootstrap sample. Correspondingly, in the ‘Physical inactivity 50%’ scenario, 50% of persons in the lowest activity category were moved to the higher activity category. In the ‘BMI50%’ scenario, all BMI values above 25 were replaced by the average of the BMI value and 25, thus reducing half of the excess weight. For example, for an individual with BMI 32 the BMI value was replaced by the value 28.5. The scenarios were chosen to illustrate the importance of prevention by demonstrating theoretical contribution of risk factors to the burden of immobility. Second, all risk factors were modified at the same time either by 50% or 100%, respectively. In the ‘All risk factors, 50%’ scenario each risk factor was changed by 50% as described above. In the ‘All risk factors, 100%,’ all individuals who smoked were moved to the non-smoking category and all physically inactive individuals to the higher category, and all BMI values above 25 were moved to the value of 25. The risk factor values were modified at the years 2011, 2022, and 2033 before projecting the next projection point. After the risk factors had been modified, they were assumed to follow the same transition probabilities as in the null scenario, over the next 11-year period. In all scenarios, including the null scenario, mortality was assumed to decrease at the same pace as in the periods 1987–1991 and 2007–2011. The contrasts between the null scenario and the other scenarios were calculated as the differences in each of the 36 imputed datasets. Further details on statistical methods can be found in the Supplementary material.

RESULTS

Transition probabilities 2000–2011

Severe mobility limitations

Mortality was much higher among those who had severe mobility limitations in 2000 compared to those without limitations at baseline, except in the oldest age group (Figure 1). The probability of moving from severe (major difficulties/not able) to mild (minor difficulties or not at all) mobility limitations decreased with age (Figure 1a). Almost half of those aged 62 years or less at

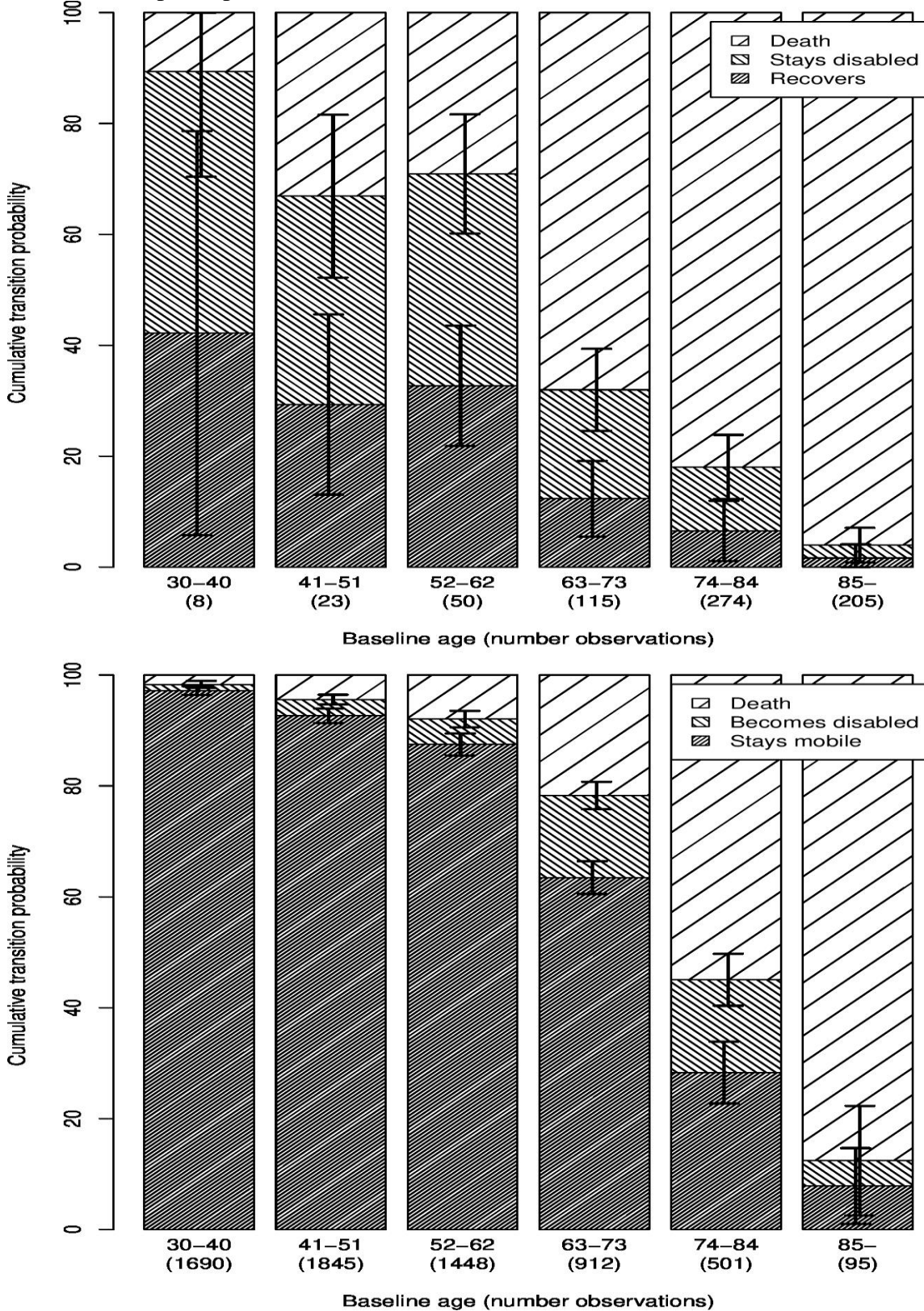
baseline who survived till 2011 recovered from severe mobility limitations, but only a third of the older persons recovered. On the other hand, the incidence of severe mobility limitations increased up to the age-group 74–84 years: only a few percent of the younger survivors but more than a third of persons aged 74–84 years developed severe mobility limitations during the 11-year follow-up (Figure 1b).

Figure 1. Transition probabilities among persons a) with and b) without severe mobility limitations at baseline by age group at baseline^{*)}.

a) Persons with severe mobility limitations at baseline (upper figure)

b) Persons without severe mobility limitations at baseline (lower figure)

^{*)} Numbers of participants are within the braces.



Obesity

No mortality differences between initially obese and non-obese persons were found in any age group (Table 1). Up to the age group 41–51 years the transitions from obesity to no obesity and vice versa were almost as likely, but in the older age groups, loss of weight was more likely.

Table 1. Crude transition probabilities (%) from one risk factor category to the other or to death, during the follow-up from year 2000 to 2011 and number of observations in 2000 in different age groups.

Risk factor	Year 2000			Year 2011		
	Age group	Risk factor present	n ^{a)}	%		
				No	Yes	Dead
Smoking ^{b)}	30–40	No	1,229	93.9	4.8	1.3
		Yes	469	29.8	67.2	3.0
	41–51	No	1,303	93.6	3.4	3.0
		Yes	566	30.3	60.8	8.9
	52–62	No	1,160	92.6	1.4	6.0
		Yes	340	38.2	44.3	17.5
	63–73	No	899	76.1	0.7	23.2
		Yes	127	25.6	21.2	53.2
	74–84	No	728	37.8	0.3	61.9
		Yes	44	6.7	5.3	88.0
85-	No	279	6.4	0.1	93.5	
	Yes	12	9.6	0.0	90.4	
Physical inactivity ^{c)}	30–40	No	1,165	78.3	20.0	1.7
		Yes	430	45.7	52.4	1.9
	41–51	No	1,306	75.6	20.2	4.2
		Yes	460	36.4	57.2	6.5
	52–62	No	1,106	77.0	16.2	6.8
		Yes	321	40.2	45.0	14.8
	63–73	No	718	53.3	24.1	22.5
		Yes	238	18.0	42.3	39.8
	74–84	No	317	23.4	23.2	53.4
		Yes	343	4.9	20.4	74.7
85-	No	39	7.1	3.4	89.6	
	Yes	157	0.8	4.6	94.6	
Obesity ^{d)}	30–40	No	1,456	86.2	12.1	1.7
		Yes	225	12.3	85.5	2.1
	41–51	No	1,481	83.4	12.0	4.6
		Yes	375	12.5	81.8	5.7
	52–62	No	1,063	81.3	10.3	8.4
		Yes	426	22.4	68.5	9.2
	63–73	No	714	67.6	5.8	26.6

	Yes	297	21.3	51.1	27.6
74–84	No	536	32.4	2.0	65.6
	Yes	196	19.1	22.9	58.0
85-	No	210	6.0	0.4	93.6
	Yes	33	3.7	4.0	92.4

^{a)} Observations in year 2000; ^{b)} Smoking: daily; ^{c)} Physical inactivity: no leisure time physical activity; ^{d)} Obesity: BMI \geq 30 kg/m²

Smoking

Mortality among baseline smokers was two- to three-fold compared to non-smokers in the age groups below 74 years (Table 1). The smoking cessation probabilities ranged from approximately 30% under age 52 to more than 50% in age groups 62–84. The relapse probabilities were at most 3–5% in the age groups below 51 years.

Physical inactivity

Physical inactivity was associated with increased mortality in the age groups 52+ (Table 1). Among those physically active persons at baseline, the probability to become inactive was about 20% between ages 30 and 84 years, and the corresponding probability of dying during the follow-up increased from 2% to 53%. Almost one half of the physically inactive persons aged 30–62 years at baseline became physically active, but in the older age groups the probabilities decreased and the transition to death increased rapidly.

Projections 2011–2044

Number of persons with severe mobility limitations

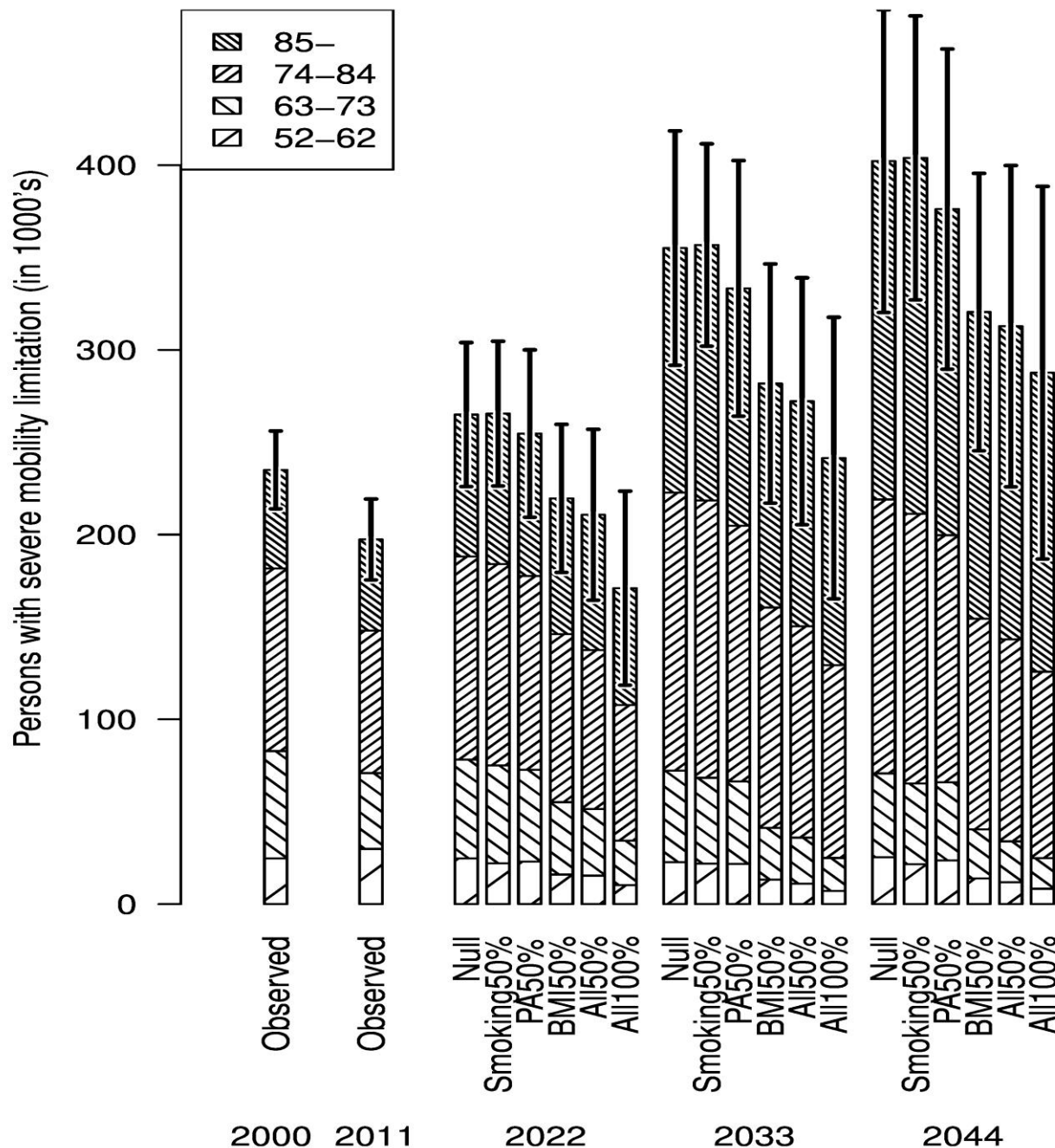
Under the null scenario the number of persons with severe mobility limitations is projected to double from year 2011 to 2044 (from 197,000 to 402,000 persons, 104% increase) in the Finnish population aged 52 or over (Figure 2, Table 2). This growth rate is substantially higher than the increase in the population size, resulting in an increasing proportion of persons with disability.

Figure 2. The effect of different scenarios^{a)} on the number of persons with severe mobility limitations. Point estimates^{b)} and prediction intervals^{c)}.

^{a)} Baseline projection ‘Null’, Physical inactivity abbreviated as ‘PA’, ‘All risk factors, 50%’ as ‘All50%’, and ‘All risk factors, 100%’ as ‘All100%’

^{b)} Averages of the 36 point estimates based on the imputed data sets

^{c)} 95% prediction intervals are based on the standard deviation of the 36 point estimates



Compared to the null scenario, in the ‘BMI50%’, ‘All risk factors, 50%’ and ‘All risk factors, 100%’ scenarios the number of persons with severe mobility limitations appear to decrease in all projection years (Table 2). This is seen in the age groups 52 to 84 years (Supplementary Table S9). In the oldest age group (aged 85 or above), the number of cases will increase multifold in all scenarios, mainly due to the rapid increase in the population size, but the small sample size hinders interpretation of the projections. The ‘BMI50%’ scenario appear to reduce the number of persons with severe mobility limitations much more than the other single risk factor scenarios: the number of persons with severe mobility limitations would only increase by 62% during the

period 2011–2044. If half of all three risk factors could be removed (scenario ‘All risk factors, 50%’), the increase would be slightly lower, 59%. Even if excess weight, smoking and physical inactivity could all be completely eliminated (scenario ‘All risk factors, 100%’), the increase would be 46%.

Table 2. Effects of different scenarios on the number of persons with severe mobility limitations, prevalence of mobility limitations and population size in years 2022, 2033 and 2044, in the Finnish population aged 52+ with 95% prediction intervals (PI).

Year	Persons with severe mobility limitations	Prevalence of severe mobility limitations	Population size
	n in 1000's (PI)	% (PI)	n in 1000's (PI)
2000	231 (214, 248)	14.4 (13.3, 15.5)	1604
2011	197 (175, 219)	10.0 (8.9, 11.1)	1980
2022			
Null ^{a)}	265 (226, 304)	11.6 (9.9, 13.2)	2293 (2256, 2329)
Smoking50% ^{b)}	265 (226, 305)	11.5 (9.8, 13.1)	2317 (2283, 2351)
PA50% ^{b)}	255 (209, 300)	11.0 (9.1, 13.0)	2307 (2266, 2348)
BMI50% ^{c)}	220 (180, 260)	9.6 (7.9, 11.3)	2290 (2253, 2327)
All risk factors,50% ^{b,c)}	211 (164, 257)	9.1 (7.1, 11.1)	2323 (2286, 2360)
All risk factors,100% ^{d)}	171 (118, 224)	7.3 (5.1, 9.5)	2333 (2229, 2437)
2033			
Null	355 (292, 419)	14.7 (12.2, 17.1)	2418 (2352, 2485)
Smoking50%	357 (302, 412)	14.5 (12.3, 16.6)	2463 (2400, 2527)
PA50%	333 (264, 402)	13.7 (10.9, 16.4)	2440 (2358, 2522)
BMI50%	282 (217, 347)	11.6 (9.0, 14.3)	2419 (2354, 2484)
All risk factors,50%	272 (205, 339)	10.9 (8.3, 13.6)	2490 (2421, 2559)
All risk factors,100%	241 (165, 318)	9.6 (6.6, 12.6)	2516 (2376, 2655)
2044			
Null	402 (320,484)	16.4 (13.3, 19.6)	2447 (2354, 2540)
Smoking50%	404 (327,481)	16.1 (13.2, 19.0)	2506 (2423, 2590)
PA50%	376 (290,463)	15.2 (11.9, 18.5)	2474 (2373, 2574)
BMI50%	320 (245, 396)	13.0 (10.1, 16.0)	2456 (2370, 2543)
All risk factors,50%	313 (226, 400)	12.3 (8.9, 15.7)	2547 (2459, 2635)
All risk factors,100%	288 (187, 388)	11.2 (7.4, 15.0)	2570 (2419, 2721)

^{a)} between 2011 and 2044 the risk factors and mobility limitations were assumed to change with the same transition probabilities as between 2000 and 2011

^{b)} 50% of individuals in the high-risk category were moved to the low-risk category (nonsmoker or moderate PA) in years 2011, 2022, and 2033; otherwise the risk factors were assumed to change with the same transition probabilities as between 2000 and 2011

^{c)} all BMI values above 25 were replaced by the average of the BMI value and 25 in years 2011, 2022, and 2033; otherwise the subjects' BMI was assumed to change similarly as between 2000 and 2011

^{d)} all individuals in the high-risk categories were moved to the low-risk categories (nonsmoker or moderate PA) and all BMI values above 25 to 25 in years 2011, 2022, and 2033; otherwise the risk factors were assumed to change with the same transition probabilities as between 2000 and 2011

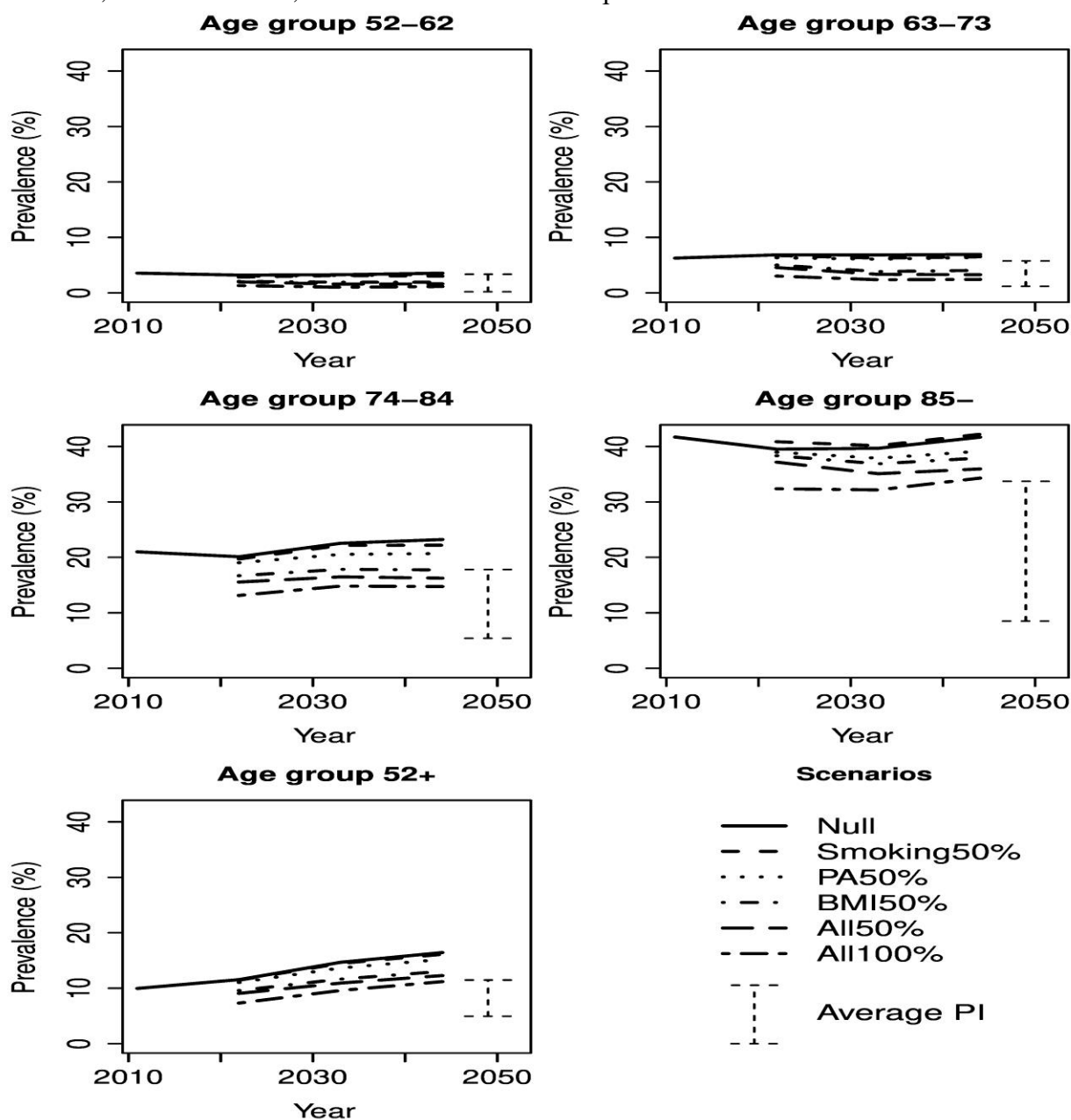
bold = the 95% credible interval of the contrast of the scenario and the null scenario did not contain zero

Prevalence of severe mobility limitations

The projected prevalence of severe mobility limitations in the age group 52 years or older will increase from 10% in 2011 to 16% in 2044, due to the rapidly growing size of the older population (Table 2, Figure 3). The projections based on the ‘BMI50%’ scenario suggest that the prevalence will be about 20% lower than in the null scenario. The difference will be greatest among persons aged 74–84 years (Supplementary Table S9). The ‘Smoking50%’ and ‘Physical inactivity50%’ scenarios appear to have no significant impact on the prevalence of mobility limitations. The ‘All risk factors, 100%’ scenario results in the lowest projected prevalence of mobility limitations. The prevalence changes paralleled the changes in the number of persons with mobility limitations, as the population size was not markedly affected by any of the scenarios.

Figure 3. The effect of different scenarios^{a)} on the prevalence of severe mobility limitations in years 2022, 2033 and 2044, by age group.

^{a)} Baseline projection ‘Null’, Physical inactivity abbreviated as ‘PA’, ‘All risk factors, 50%’ as ‘All50%’, ‘All risk factors, 100%’ as ‘All100%’ and ‘prediction interval’ as ‘PI’



DISCUSSION

Our projections demonstrate that the number of persons with severe mobility limitations is likely to double from 200,000 persons in 2011 to 400,000 persons by 2044 in Finland and the prevalence of severe mobility limitations to increase from 10 to 16.4 % if the risk factors and mobility limitations continue developing similarly as during the period from 2000 to 2011. This estimated rapid increase has potential to be markedly slowed down by eliminating half of the excess weight: both the number of persons and the prevalence of severe mobility limitations would reduce by one fifth. Changes in smoking and physical activity had little effect on the projections. This can be attributed to the selection by the higher mortality of smokers and physically inactive individuals. Moreover, there is a two-way association between obesity and physical activity,[36] and BMI, which is measured more accurately, may partly overrule the effect of physical activity. Due to population aging, the number of persons with severe mobility limitations is expected to increase even if all the most essential behavioral risk factors were to be eliminated.

Our projection on the increase of the number of persons with mobility limitations is well in line with the calculations by Smith et al.[23] Projections concerning mobility limitations are rare, even though mobility restrictions are common in old age and precede difficulties in activities of daily living and need of care.[3,4,37] We chose mobility limitations as an outcome since its risk factors are well established. Our assumption on eliminating all risk factors is unrealistic, but our results suggest that reducing excess weight by half would yield more than two-thirds of the positive outcome generated by completely eliminating all three risk factors.

Several researchers have raised the question of the deteriorating health of the younger generations, which in turn affects the future disability rates.[7,10,12] In projections spanning several decades into the future, it is important to project also the risk factor distributions of the presently young population so as to incorporate their influence on disability. Previous studies[25] have mainly focused on older people, while our analyses included all persons aged 19 or over.

Our method uses longitudinal data, which allow us to take account of the dynamic transitions in the major risk factors and mobility limitations, as well as the interactions both between the predictors and with education. Our projections also take into account the future development of the educational structure and allow for differential survival in the educational groups. A strong association between education and health-related outcomes, including disability[38-40] has been shown, and changes in the educational structure of the population contribute to past[9] and future[14,21,25] estimates of disability. Another strength in our study is that we accounted for the uncertainty inherent in all predictions. We report the uncertainty using prediction intervals, which accommodate the different sources of uncertainty. The more distant future we are predicting, the wider these intervals get.

There are a few limitations in the present study. Our approach considers only three individual risk factors affecting disability rates. We were not able to cover other individual risk factors, e.g. binge drinking, nor environmental adaptations, such as assistive device use, accessible housing and public transportation, or various social factors, which may also have a large impact on future disability rates [41,42]. Our projections did not account for immigration, which will increase the number of people with disabilities later, as those immigrants have aged. We assumed a fixed decreasing trend in mortality, which might not continue in the future. Mortality being higher or lower would affect the projections. The moderate response rate can cause selection bias. However, the response rate at baseline was high (92%), allowing for a quite accurate imputation of the missing outcome and risk factor values in 2011.[31] As our results were based on an observational study, the projections based on different scenarios do not necessarily reflect the causal effects of risk factor changes, which would require incorporation of randomized controlled trials and evidence synthesis.[43,44]

In conclusion, the number of people with severe mobility limitations is likely to double in the coming decades in Finland. This increase is mainly due to the aging of the population and will lead to substantial societal and economic consequences, such as increasing care needs and long-term care expenditure and changing demands for the housing industry.[23] Nevertheless, by reducing excess weight, the rapid increase could be slowed significantly. Designing and implementing strategies and policies to promote healthy weight and weight reduction as well the health and wellbeing of people with mobility limitations should, therefore, be national priorities.

What is already known on this subject

- Increasing trends in mobility limitations have raised concern about future financing of services for older people.
- Projections on future development of mobility limitations are rare and have not investigated the impact of changes in modifiable risk factors.

What this study adds

- By applying multistate modelling this study accounts for individual changes in risk factors over time, and how these factors may influence mortality and mobility; the different sources of uncertainty in projections are also accounted for.
- Mobility limitations are projected to increase considerably due to population ageing, but reductions of excess weight would markedly slow the rapid increase.
- Healthy public policy should prioritise allocating resources to maintaining functional ability and to provision of adequate services for persons with disabilities.

Contributions: TH and PS contributed equally in the manuscript preparation. TH, PS and SK participated in concept and design, and all authors participated in interpretation, writing, and approved the final version.

Competing interests: None declared.

Funding

This work was supported by the Academy of Finland (grant numbers 266251, 286294, 294154, 307907).

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