Actuaries Institute.

Power in numbers

The collaboration of injury & disability schemes in understanding impaired lives mortality

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What we'll cover today

Purpose

Modelling

Results

Purpose

Setting the Scene

Injury and disability schemes

Provides lifetime care and support to catastrophically injured individuals, particularly those with:

Traumatic Brain Injury (TBI)

Spinal Cord Injury (SCI)

Their mortality rates are known to be significantly higher than those of the general population **– but by how much?**

Assumed TBI and SCI mortality rates

Critical input to actuarial valuations

Drives liability estimates and determining levies and funding requirements

Although higher mortality is well recognised, the size of this excess mortality in the Trans-Tasman context has **not been clearly established.**

The Study

Finity initiated and led a **collaboration between nine injury and disability schemes** across AU and NZ

Enabling a **large population** to be studied

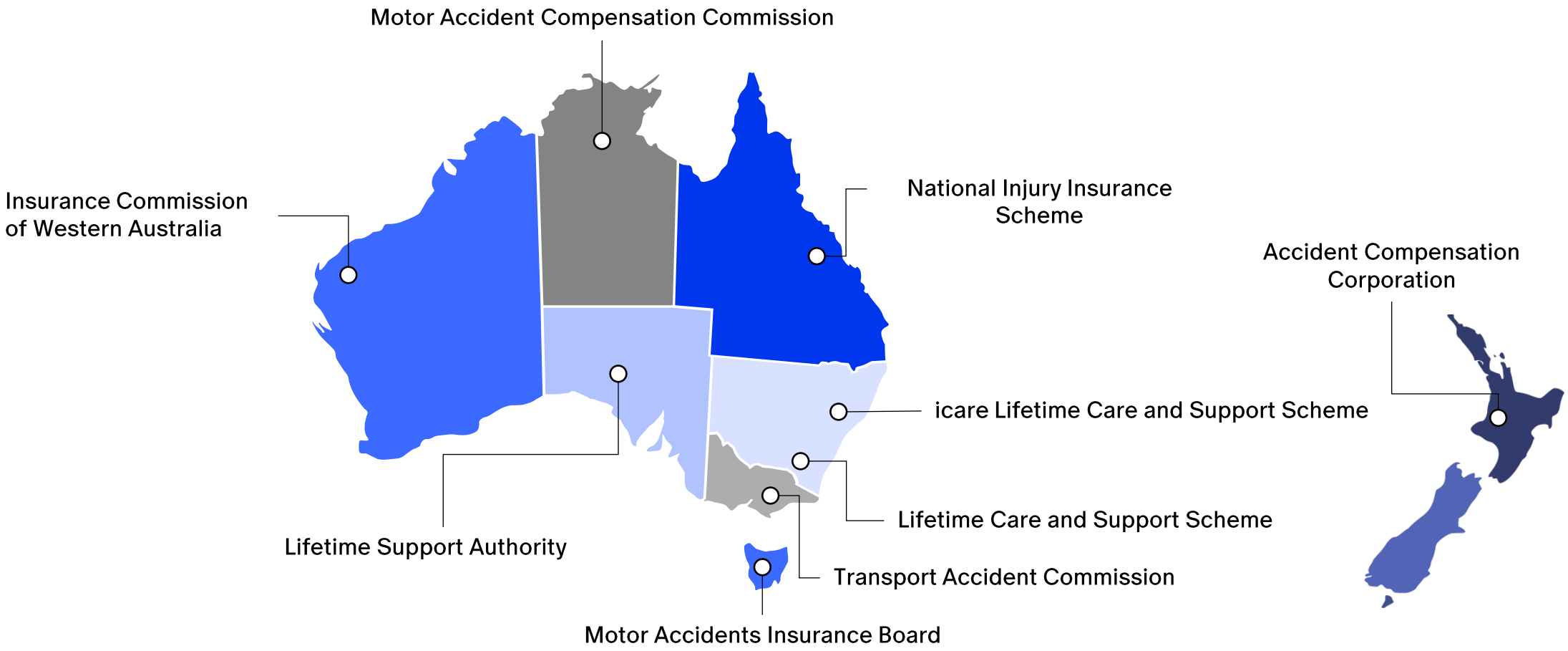
Facilitating **more reliable analysis** of mortality experience than individual scheme's data allows

Reducing reliance on published studies which may be dated, international, or otherwise not fully comparable to the cohort

The study delivers **Trans-Tasman specific mortality benchmarks** that schemes can use as a robust basis for developing mortality assumptions

Participating schemes

We are grateful to the following schemes for participating in this mortality study



Modelling

02

How we model mortality

Rather than modelling the mortality rate *directly*, we quantify the ***relative mortality***

$$\text{Standardised mortality ratio (SMR)} = \frac{\text{Observed deaths in TBI or SCI cohorts}}{\text{Expected deaths based on population mortality rates}}$$

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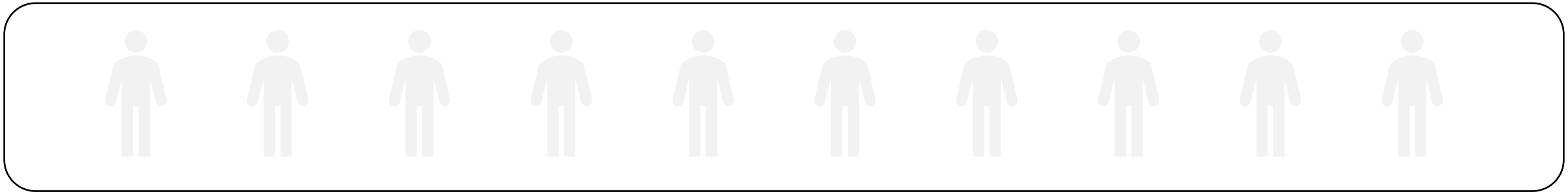

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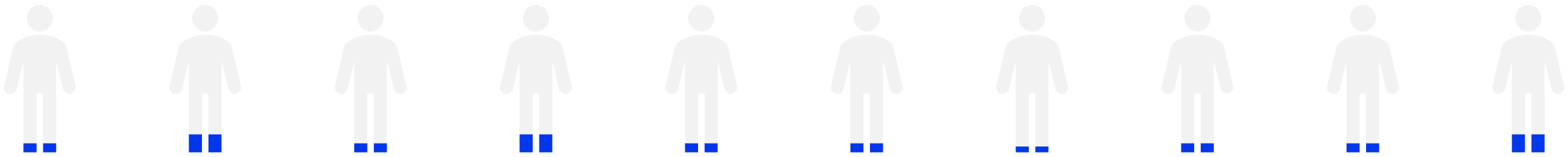

Key Population mortality rate

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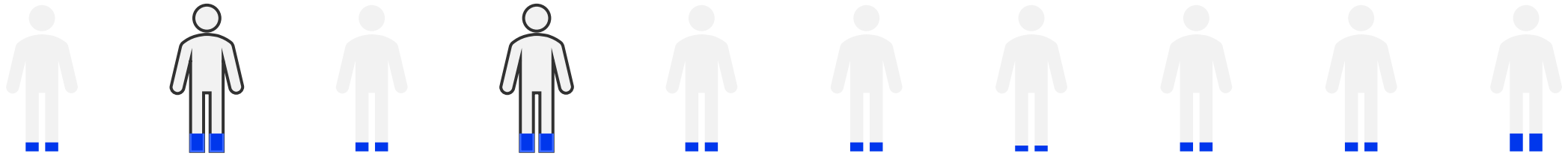


Key Population mortality rate Observed deaths

SMR = 2/0.7 = 2.86

Literature review on mortality after TBI and SCI

We reviewed...

TBI	**19** papers Published between 2005 - 2022	**SCI**	**17** papers Published between 2010 - 2020

Key Findings

Elevated mortality

Studies consistently show mortality well above general population

Reported SMRs vary widely by cohort, follow-up, and methodology

Key

Age

Gender

Pre-existing health conditions

Injury severity
- Functional disability (TBI)
- Lesion level / completeness / ventilator dependence (SCI)

Socio-economic status (SCI)

Temporal trends

Studies consistently report no significant improvement in mortality rates for individuals with TBI or SCI

Because general population mortality has improved while TBI/SCI mortality has not, SMRs have risen over time.

Study design and methodology

Statistical methods and modelling approaches vary across studies

Study cohorts differ from our setting, limiting comparability

However, published SMRs **are not directly applicable** to scheme-accepted participants in the Trans-Tasman context, highlighting the need for this study.

How we model mortality

Rather than modelling the mortality rate *directly*, we quantify the ***relative mortality***

$$\text{Standardised mortality ratio (SMR)} = \frac{\text{Observed deaths in TBI or SCI cohorts}}{\text{Expected deaths based on population mortality rates}}$$

Key Ingredients

1. **Population mortality tables** — Age-, gender-, year- and jurisdiction-specific population life tables from Australia and New Zealand
2. **Participant data** — Structured into participant-years to track follow-up time and outcomes consistently.
3. **Statistical model** — Poisson GAM framework with population expected deaths as offset, yielding SMRs that capture relative mortality.

This approach provides a coherent way to capture how relative mortality ***evolves*** with <u>underlying participant and injury characteristics</u>

Key Ingredients – Population Mortality Table

1. Population mortality tables
2. Participant data
3. Statistical model

	Australia	New Zealand
Source	**ABS life tables:** Released annually, each table covers a 3-year period (from 2002–04 to 2020-22). From 2009–11 onward also split by state/territory. **AGA life tables:** Released every 5 years, each table covers a 3-year period (from 1946–48 to 2020–22), national only.	**Statistics NZ life tables:** Released every 5 years, each table covers a 3-year period (from 1934–38 to 2017–19), national only.
Approach	**Pre-2009:** Extrapolated back using (interpolated) AGA historical trends (by age and gender) **2009-11 to 2020-22:** Used ABS (by state/territory) **2023-24:** Extrapolated forward from 2022 using annualised pre-COVID improvements observed between 2013-18	Interpolated between 5-year tables to derive annual rates **Post-2019:** Extrapolated using 2013-18 pre-COVID improvement trends **COVID impact minimal:** Negative excess mortality in 2020-23
Outcome	Constructed continuous historical sets of population mortality rates by age, gender, year and jurisdiction, forming a consistent baseline to calculate SMRs across cohorts and years	

Key Ingredients – Participant Data

1. Population mortality tables
2. **Participant data**
3. Statistical model

Data basis

Participant-level datasets received from nine schemes

Analysis based on data available up to 30 June 2024

Inclusion criteria

Injury type: Traumatic brain injury, spinal cord injury

Support needs: Individual requires lifetime care and support

Scheme inclusion: Formally accepted into the scheme

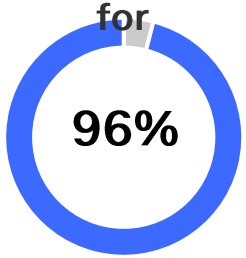
Scheme scope

Australia: Catastrophic injuries from motor vehicle accidents

New Zealand (ACC): Broader range of causes, incl. workplace accidents, sports, and maternal birth injuries

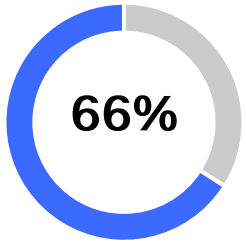
Data profile

ACC, TAC and icare account for



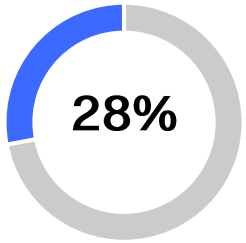
and thus drive the observed mortality experience

TBI



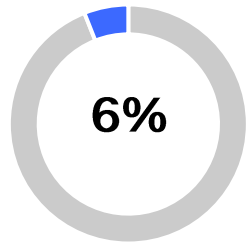
Largest injury group

SCI



2nd Largest injury group

Other



Excluded from primary analysis due to limited data

Key Ingredients – Participant Data

1. Population mortality tables
2. **Participant data**
3. Statistical model

To ensure **consistency** and **comparability** across schemes and over time, several data manipulations were applied to the datasets provided

Allows us to aggregate scheme information for mortality rate analysis

Steps in preparing participant data

Data standardisation

- Harmonised datasets to ensure consistency in structure, field definitions and format
- Conducted data validation checks to confirm completeness, logical consistency, and reasonableness.

Injury severity groups

- Reconciled different severity scales used by schemes
- Established common groupings to enable cross-scheme comparison

Participant exposure periods

- Defined exposure from scheme entry to exit, death, or 30 June 2024
- Split histories into intervals that reset on birthday, calendar year change, or injury anniversary

Key Ingredients – Participant Data

1. Population mortality tables
2. **Participant data**
   - **Data standardisation**
   - Injury severity groups
   - Participant exposure periods
3. Statistical model

While we did not independently audit or verify the information provided, we conducted a series of checks to assess the **reasonableness** and **consistency** of the data

- Completeness of Fields
- Validity of Fields
- Reconciliation with Actuarial Valuation Data
- Internal Consistency between fields
- Survivorship Bias
  - Whether dataset was representative of all deaths

Any issues identified during these checks were queried with scheme staff.
We are grateful for their valuable assistance in addressing these matters.

Key Ingredients – Participant Data

1. Population mortality tables
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   - **Injury severity groups**
   - Participant exposure periods
3. Statistical model

The Challenge

Schemes classify injury severity differently, with varying levels of detail and completeness

TBI

Severity recorded using **multiple, non-**

- Care and Needs Scale (CANS)
- Functional Independence Measure (FIM)
- Functional Code (F-code)
- Serious Injury Profile (SI Profile)

SCI

Severity recorded with **differing granularity and completeness**

- Level of Lesion (LoL)
- ASIA impairment classification (ASIA)

These inconsistencies made direct comparison across schemes **impossible without harmonisation**

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These inconsistencies made direct comparison across schemes **impossible without harmonisation**

Our Solution

Developed a **two-level hierarchy of groupings** to enable pooling of data across schemes.

	CANS	Fcode	FIM
High	6-7	1-3	18 - 48
Medium	4-5	4	49 - 109
Low	0-3	5	110+

Level 1: Base Groupings

- Broad categories to bring different scheme scales onto common ground
- Defined to maximise comparability and allow all schemes to be combined

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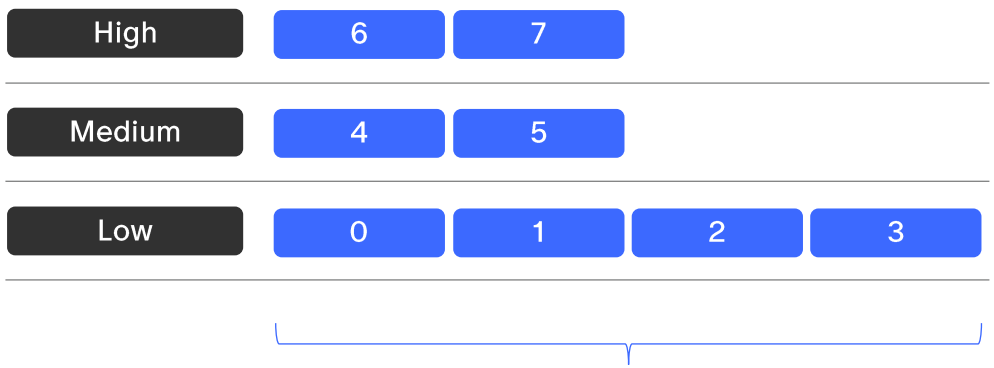
e.g. TBI - CANS



Level 1: Base Groupings

- Broad categories to bring different scheme scales onto common ground
- Defined to maximise comparability and allow all schemes to be combined

Level 2: Refinements

- Adds further splits where schemes provided more detailed information
- Provides extra insight while remaining anchored to the Level 1 structure

Key Ingredients – Participant Data

1. Population mortality tables
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3. Statistical model

Each injury classification scheme is unified into Level 1: Base Groupings

TBI

Level 1 Group	CANS	Fcode	FIM	SI Profile
High	6-7	1-3	18 - 48	
Medium	4-5	4	49 - 109	
Low	0-3	5	110+	
ACC High				5
ACC Low				6

SCI

Level 1 Group	ASIA	Level of Lesion
Complete Quad High	ASIA A-C	High quadriplegia (C1-C5)
Complete Quad Low		Low quadriplegia (C6-C8)
Complete Para		Paraplegia (below T1)
Incomplete	ASIA D	

TAC F-codes
Aligned with CANS categories using an exposure-based approach

FIM scores
Mapped to CANS categories using a clinical approach developed with disability experts

ACC data retained in its own categories, reflecting its broader coverage of injury causes compared to the Australian motor accident schemes

ASIA
Grouped as complete injuries (ASIA A-C) vs Incomplete injuries (ASIA

LoL
Complete injuries subdivided by level of lesion

Key Ingredients – Participant Data

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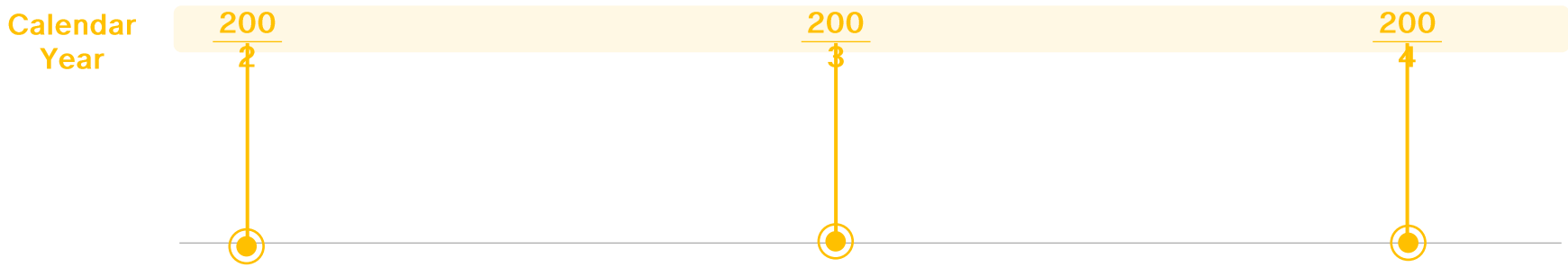
3. Statistical model

We restructure participant histories into **exposure periods** (participant-time intervals) for mortality modelling

Each period aligns with calendar year



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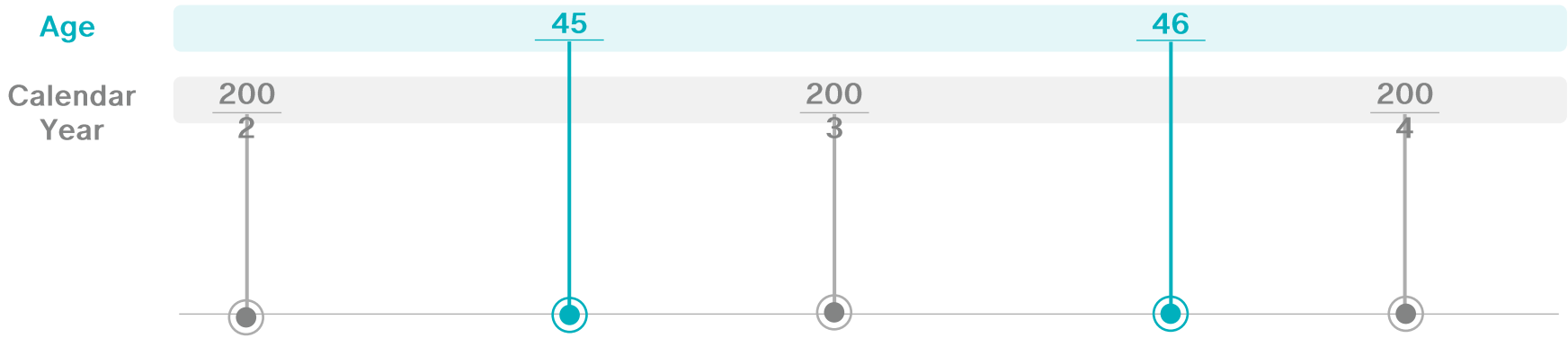
Each period aligns with calendar year, age



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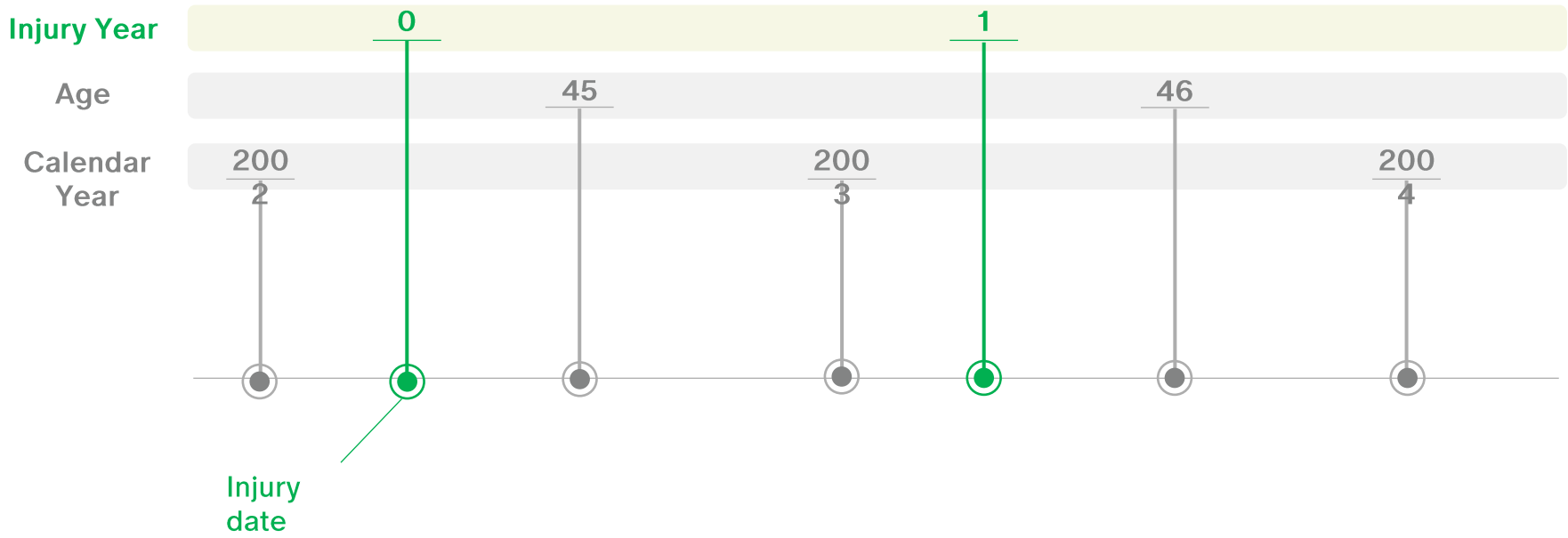
Each period aligns with calendar year, age, and time since injury



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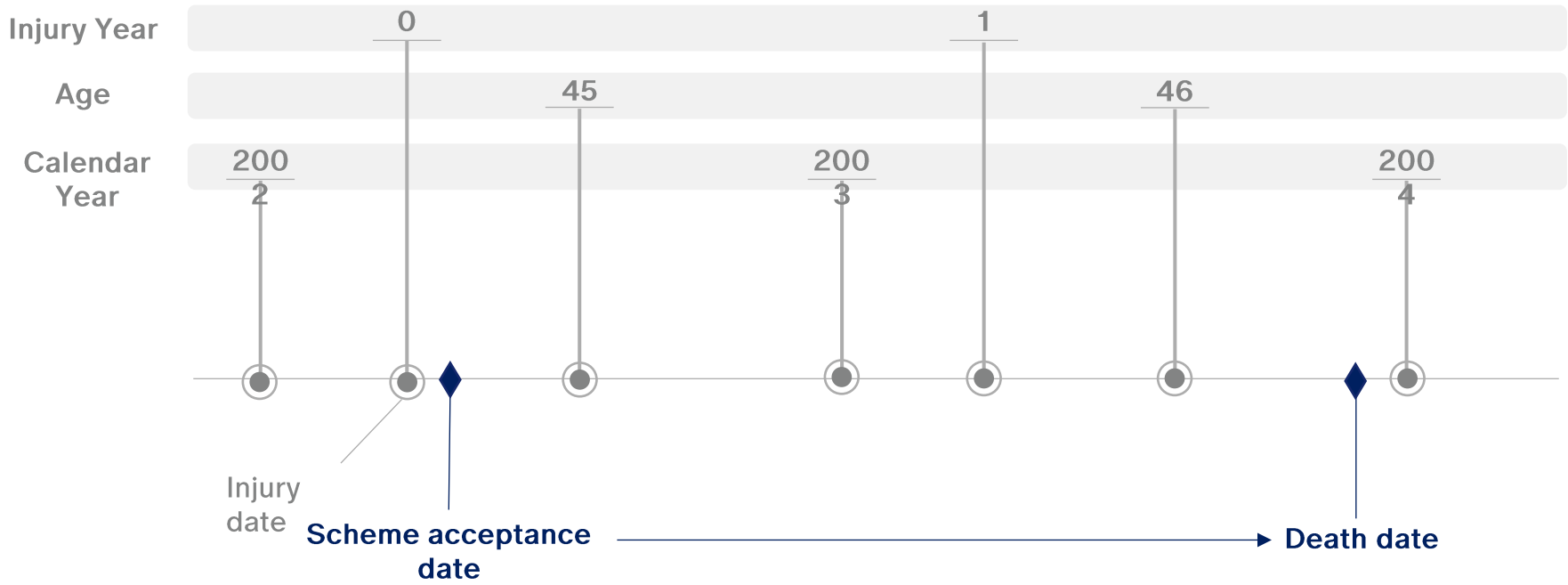

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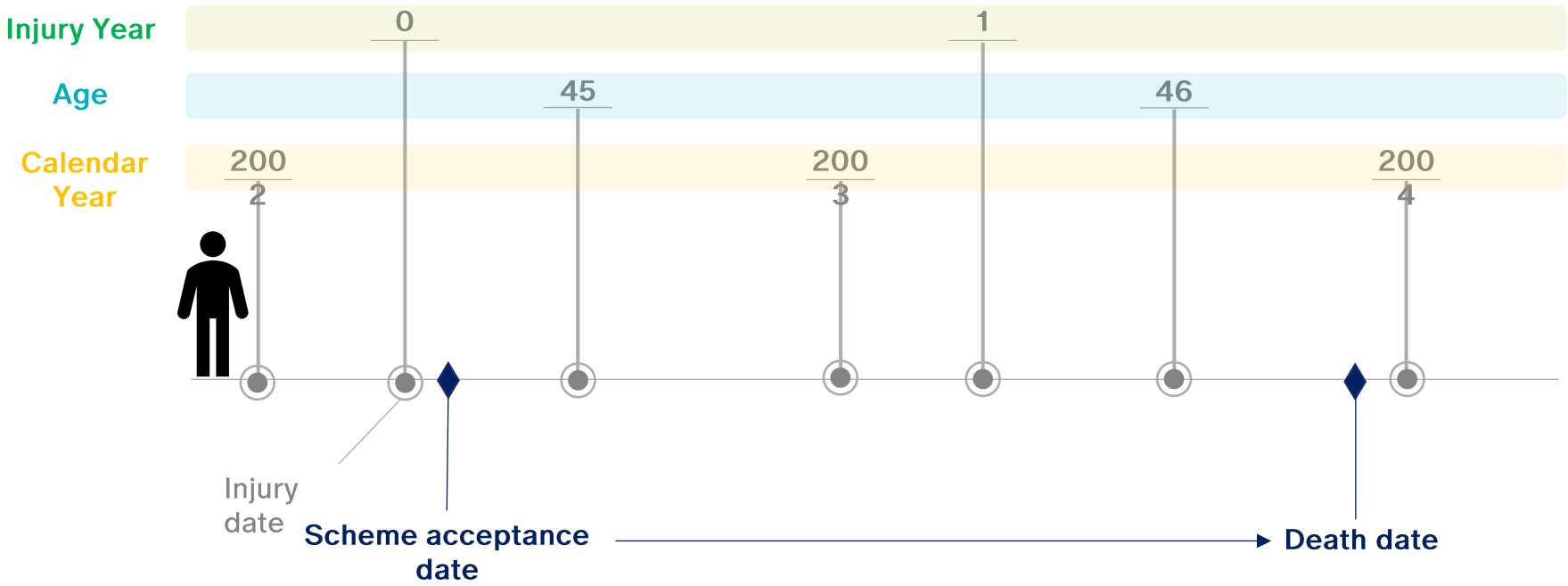

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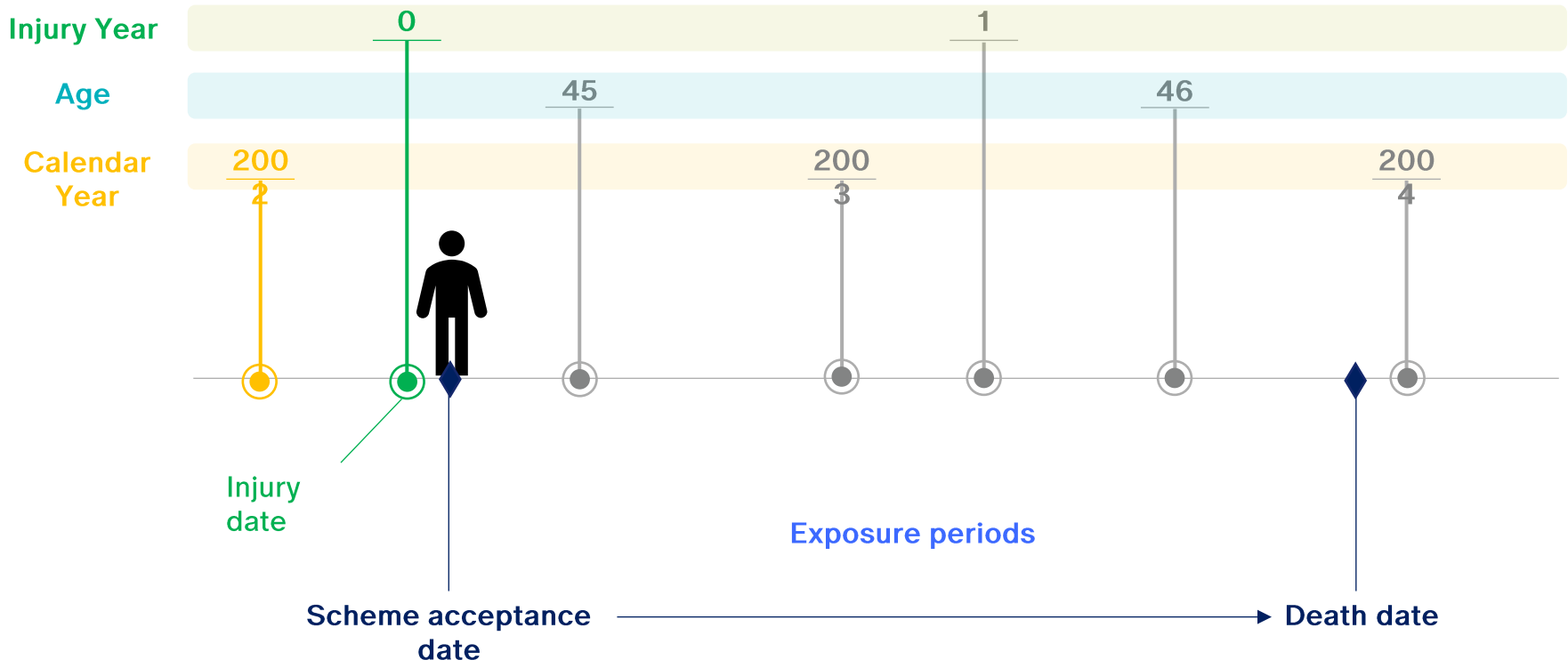

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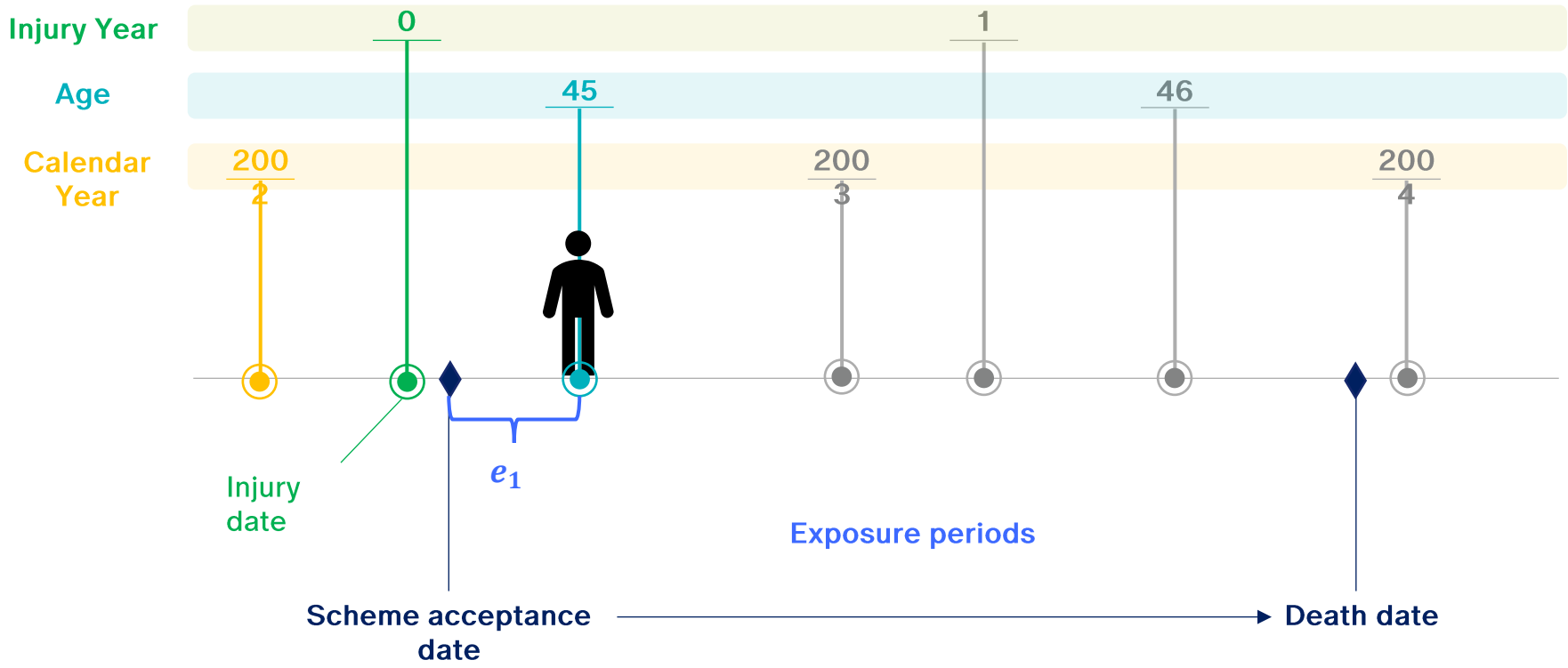

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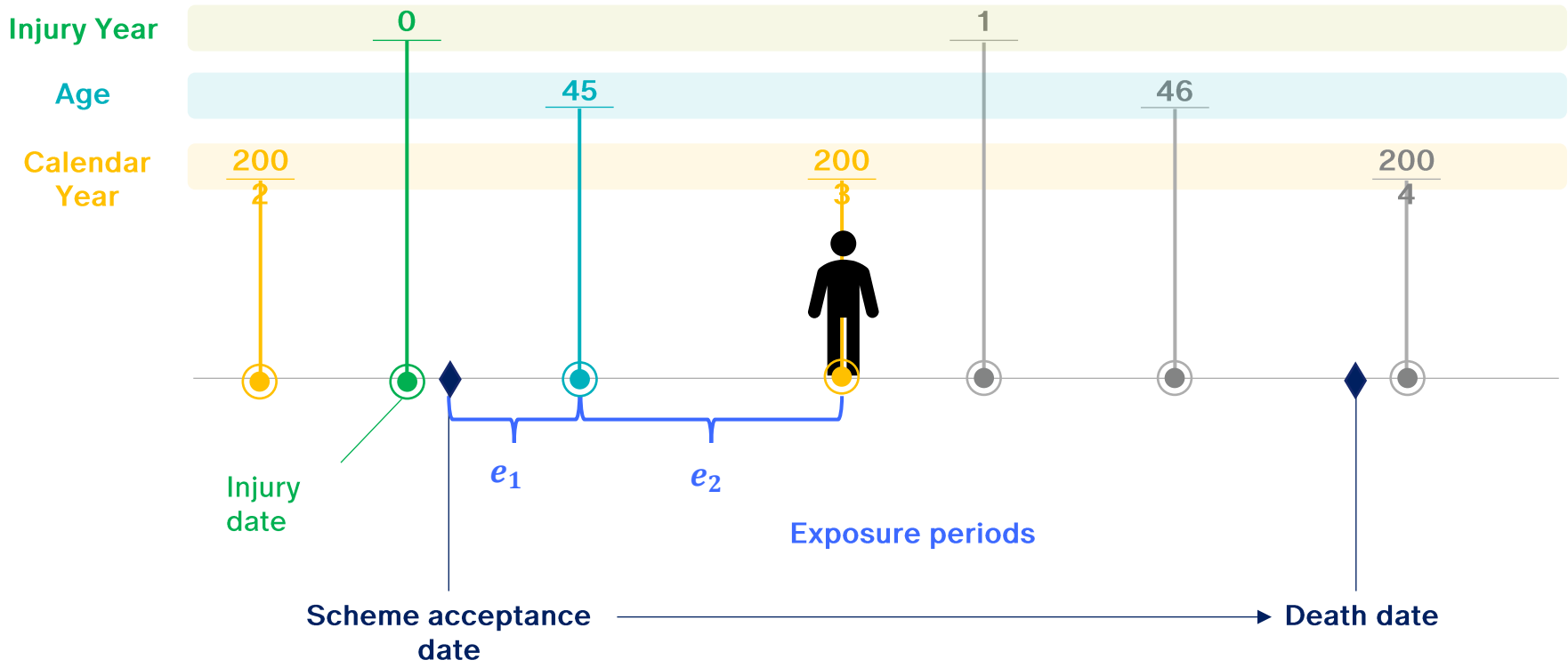

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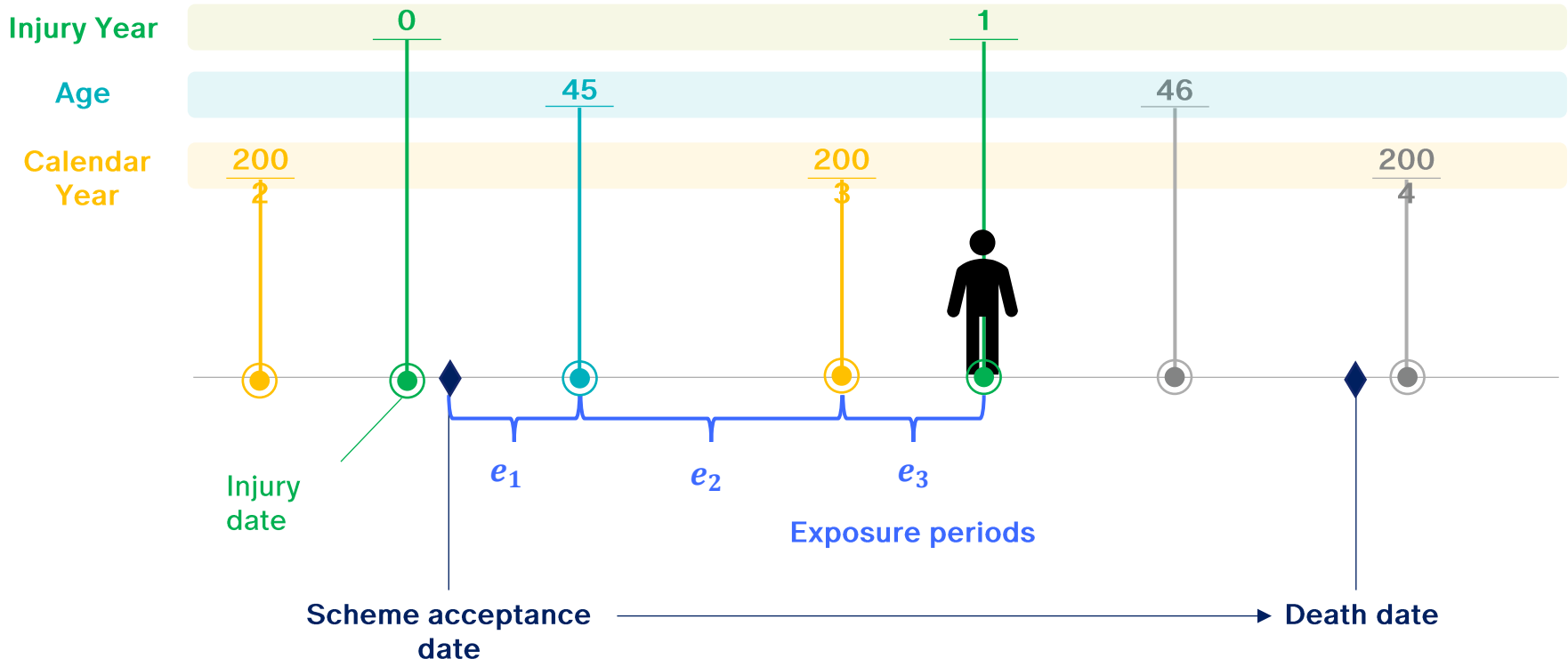

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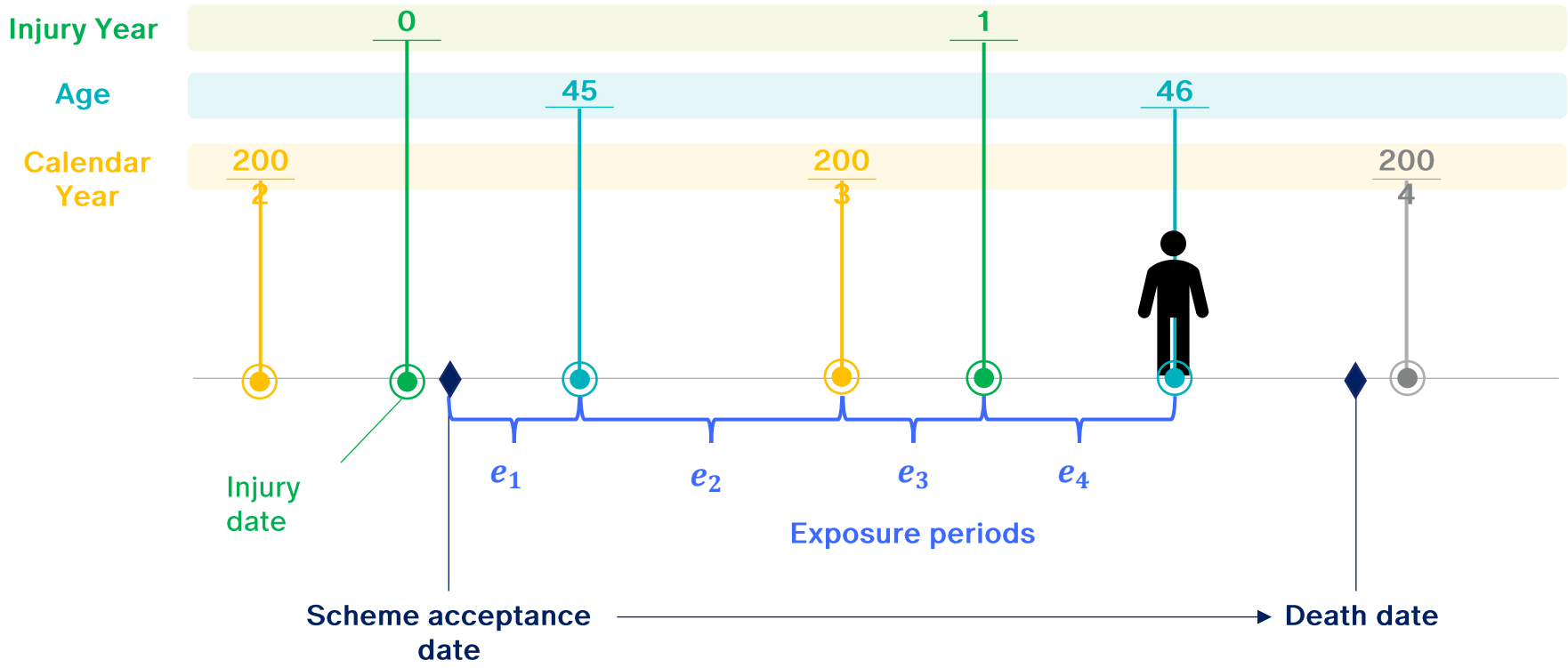

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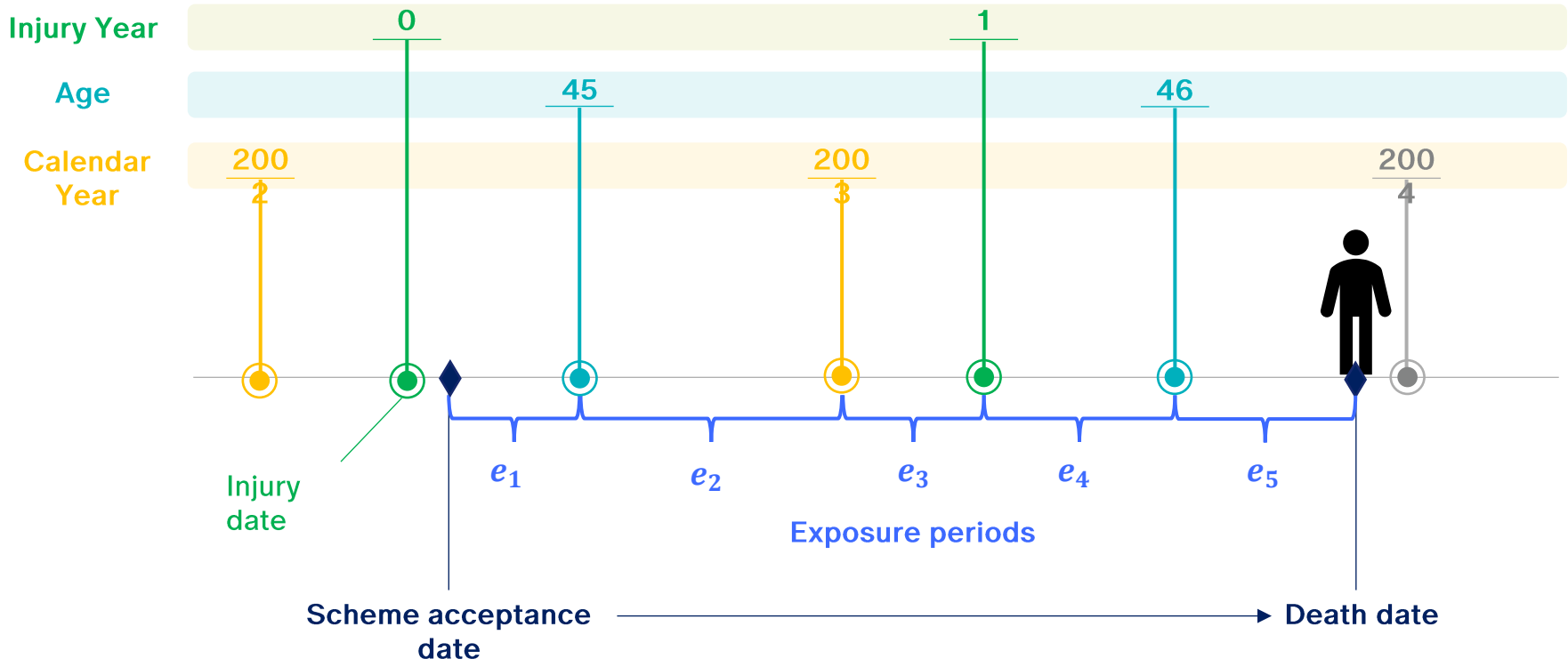

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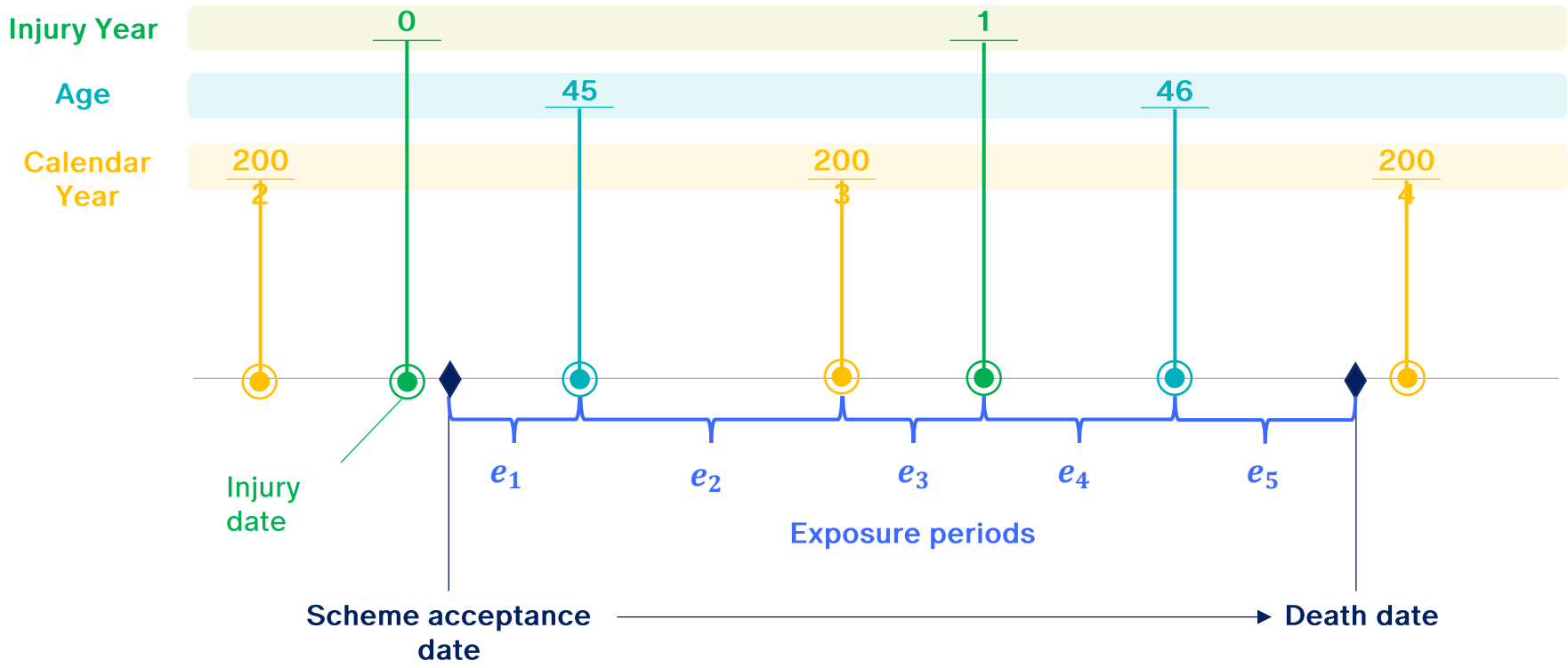

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For each exposure interval, expected deaths were derived from **general population mortality tables** – matched on age, gender, calendar year and jurisdiction

For person aged x in exposure period e_i:

q_x : one-year death probability

μ_x : constant force of mortality

$$\mu_x = -\log(1 - q_x)$$

$Y_{expected,i}$: expected deaths over the interval of duration e_i

$$Y_{\text{expected},i} = \mu_x \times e_i$$

This represents the deaths we would expect if catastrophically injured participants experienced the **same mortality as the general population**

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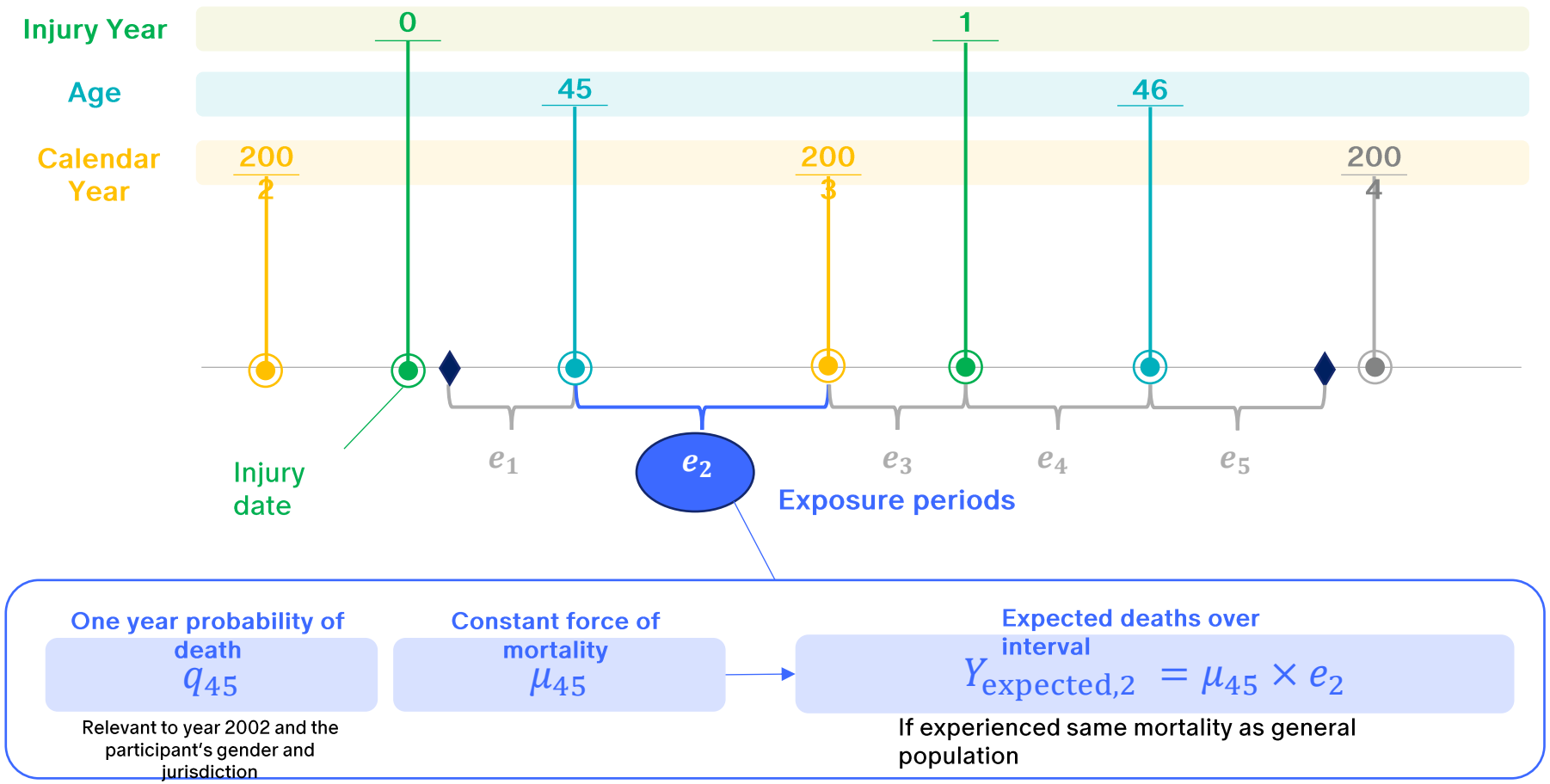

One year probability of death
q_{45}
Relevant to year 2002 and the participant's gender and jurisdiction

Constant force of mortality
μ_{45}

Expected deaths over interval
$Y_{\text{expected},2} = \mu_{45} \times e_2$
If experienced same mortality as general population

Actuaries Institute.

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This represents the deaths we would expect if catastrophically injured participants experienced the **same mortality as the general population**

Combining all participant exposure gives the following totals for the entire study

Cohort	Participants	Participants years	period Actual deaths	Expected deaths	Overall SMR
TBI	11,786	134,940	1,998	717	2.79
SCI	4,671	58,179	1,155	375	3.08

Key Ingredients – Statistical Model

1. Population mortality tables
2. Participant data
3. **Statistical model**

Modelling observed deaths $Y_{\text{actual},i}$

Observed deaths $Y_{\text{actual},i}$ in each interval are modelled as Poisson with expectation

$$\lambda_i = Y_{\text{expected},i} \times SMR_i = Y_{\text{expected},i} \times \exp(\eta_i)$$

The offset baseline expected deaths ensures estimates are relative to population mortality, so the model directly estimates the SMR

Fitting a GAM

We fit a **Poisson Generalised Additive Model (GAM)** to model the SMR as a function of the participant and injury characteristics:

$$\eta_i = \beta_0 + s_1(Age\ At\ Injury_i) + s_2(Duration\ Since\ Injury_i) + s_3(Calendar\ Year) + f_4(Injury\ Severity_i) + f_5(Gender_i)$$

Covariates were selected based on statistical and actuarial principles, literature review, and data availability

Two-stage hierarchical approach for injury severity

Base model:
Common severity groupings across all schemes

Refinement model
Adds scheme-specific severity detail, estimated with ridge-penalised effects to improve stability.

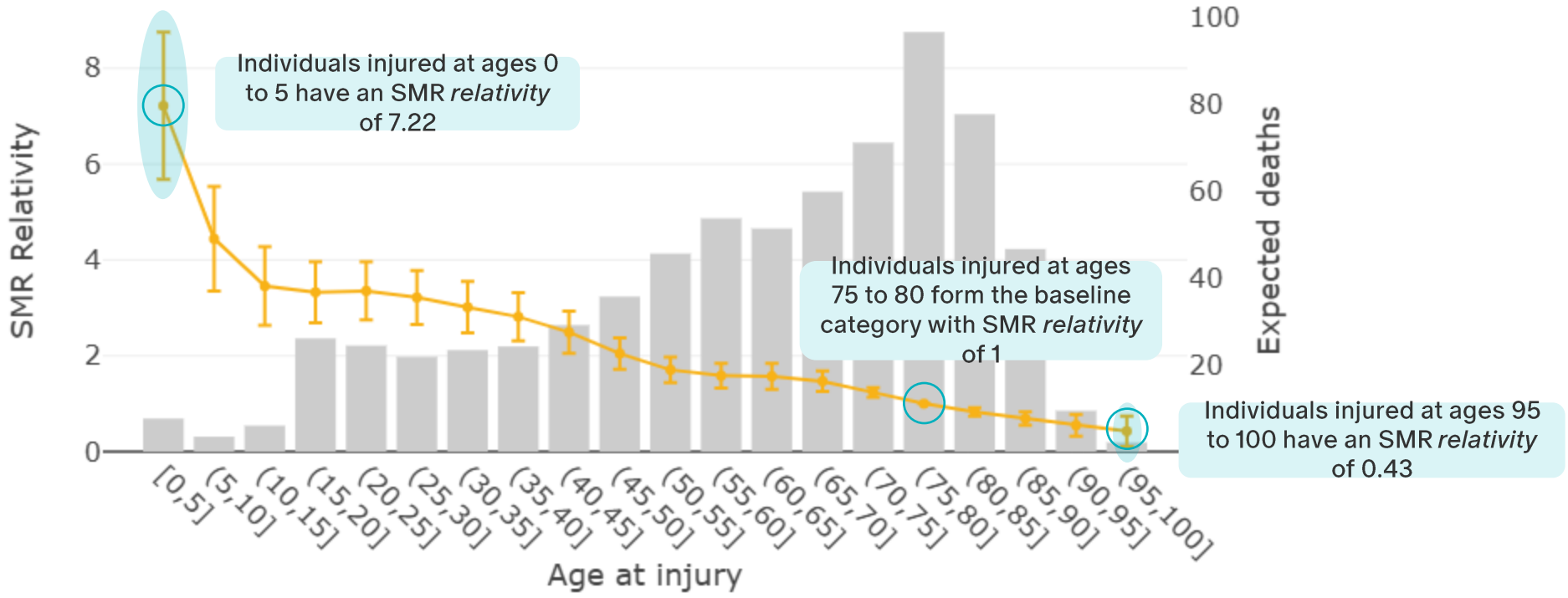
The results will be presented as partial dependence plots, showing how SMR changes with each factor, after adjusting for the others.

Results

03

Age at Injury

TBI



Decreasing relationship between age at injury and subsequent mortality risk relative to the general population

The **confidence intervals for these relativities widen at younger ages**, reflecting the lower number of deaths recorded within the study period among young individuals injured in accidents

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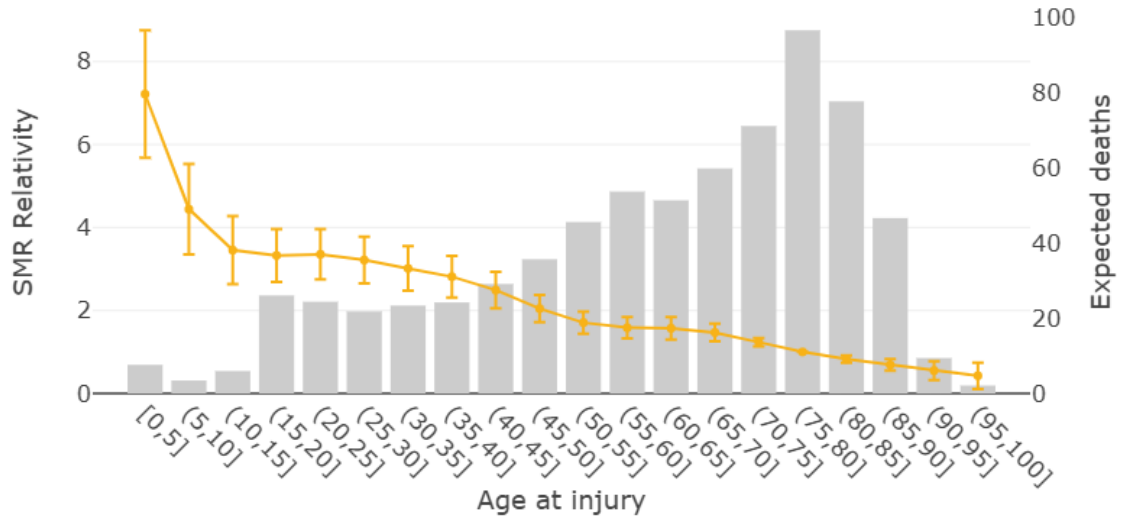
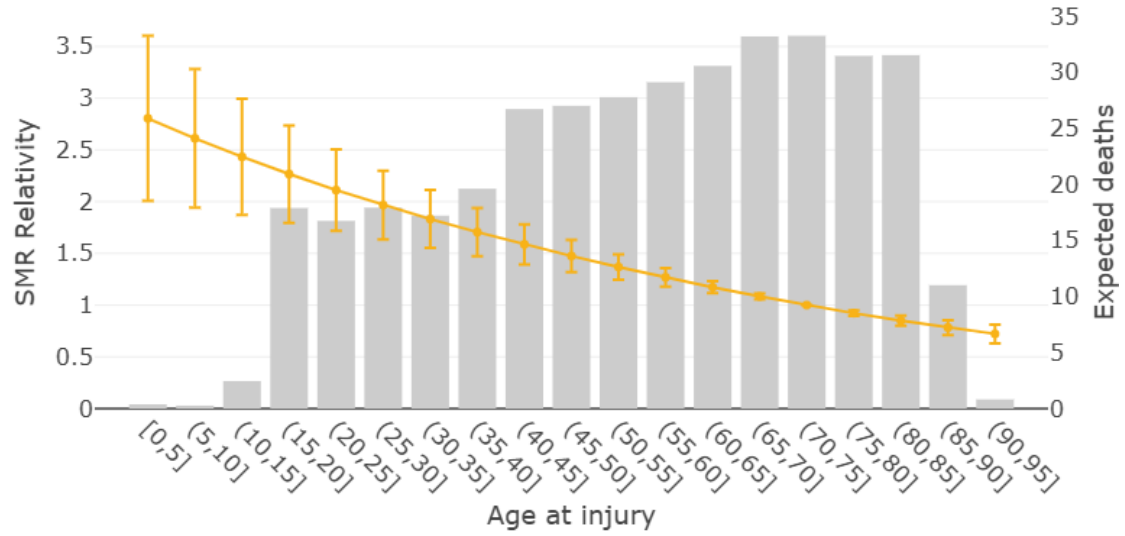
Age at Injury

TBI



SCI



Decreasing relationship between age at injury and subsequent mortality risk relative to the general population

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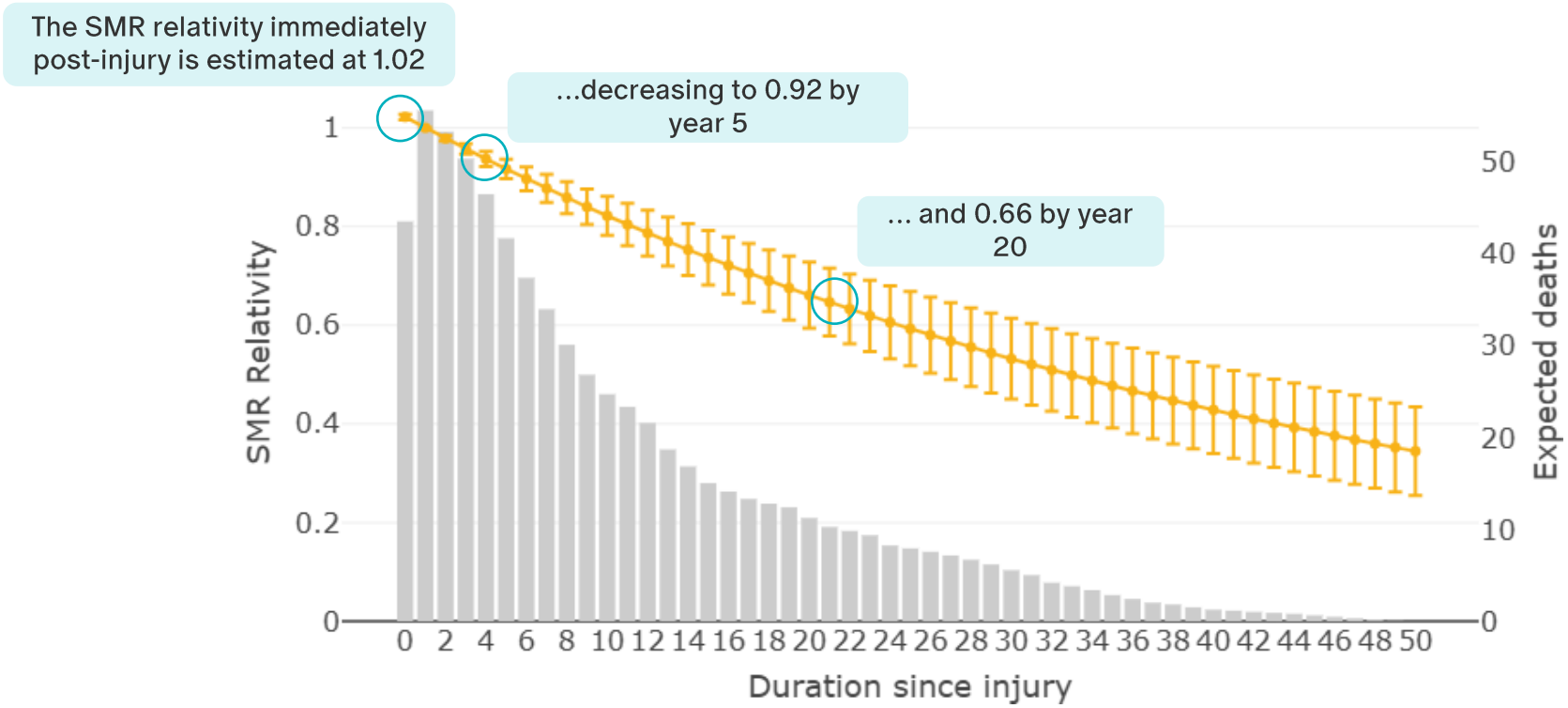
Duration since injury

TBI



The relative mortality risk is **highest immediately following the injury** and **decreases with duration.**

Use caution when interpreting the **first-year post-injury** estimates, as they reflect outcomes after scheme acceptance rather than immediate post-injury risk, and acceptance timing differs across schemes.

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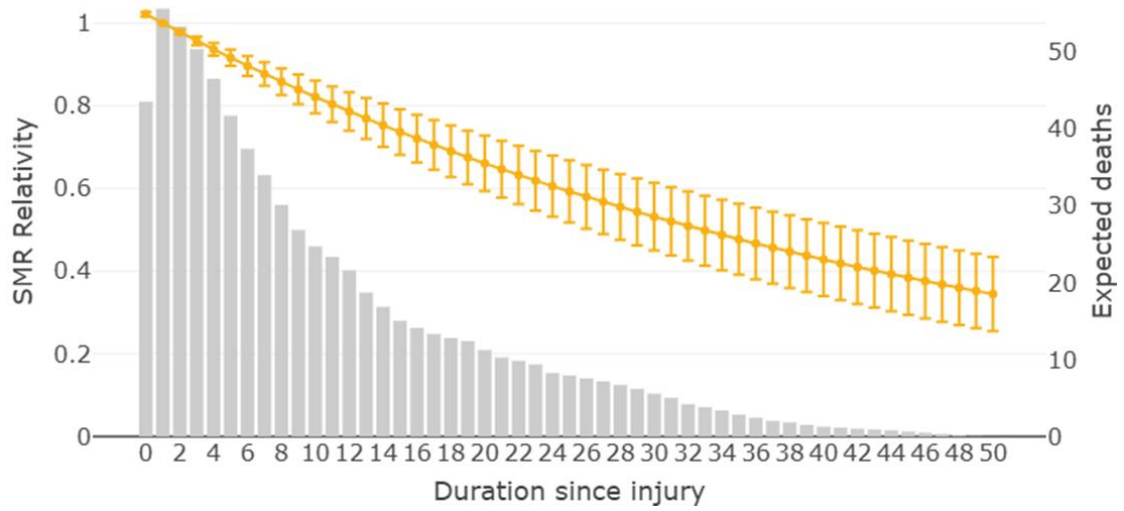
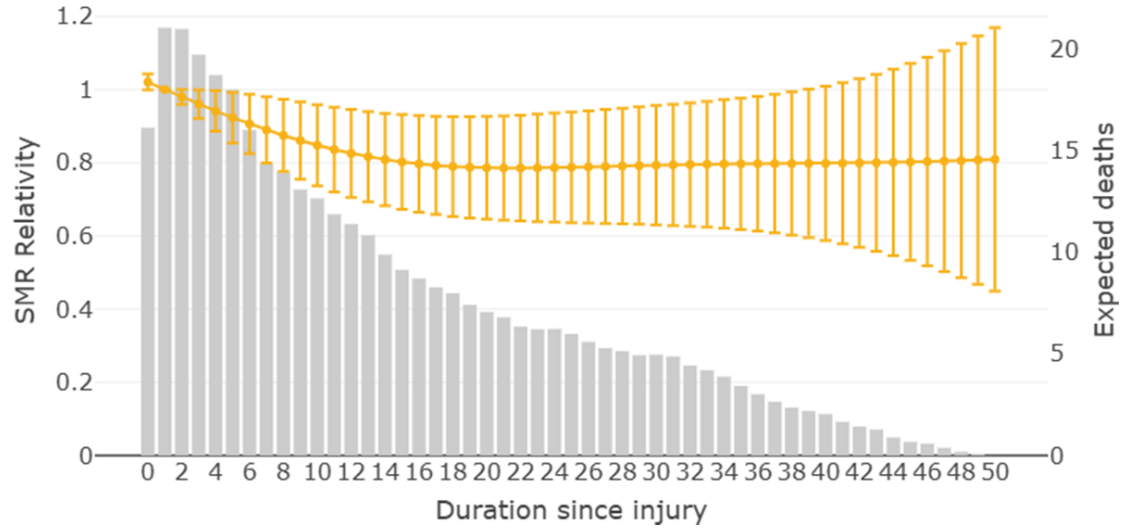
Duration since injury

TBI



SCI



The relative mortality risk is **highest immediately following the injury** and **decreases with duration.**

Use caution when interpreting the **first-year post-injury** estimates, as they reflect outcomes after scheme acceptance rather than immediate post-injury risk, and acceptance timing differs across schemes.

For SCI, we have identified that SMR tends to **stabilise 15 years post injury**.

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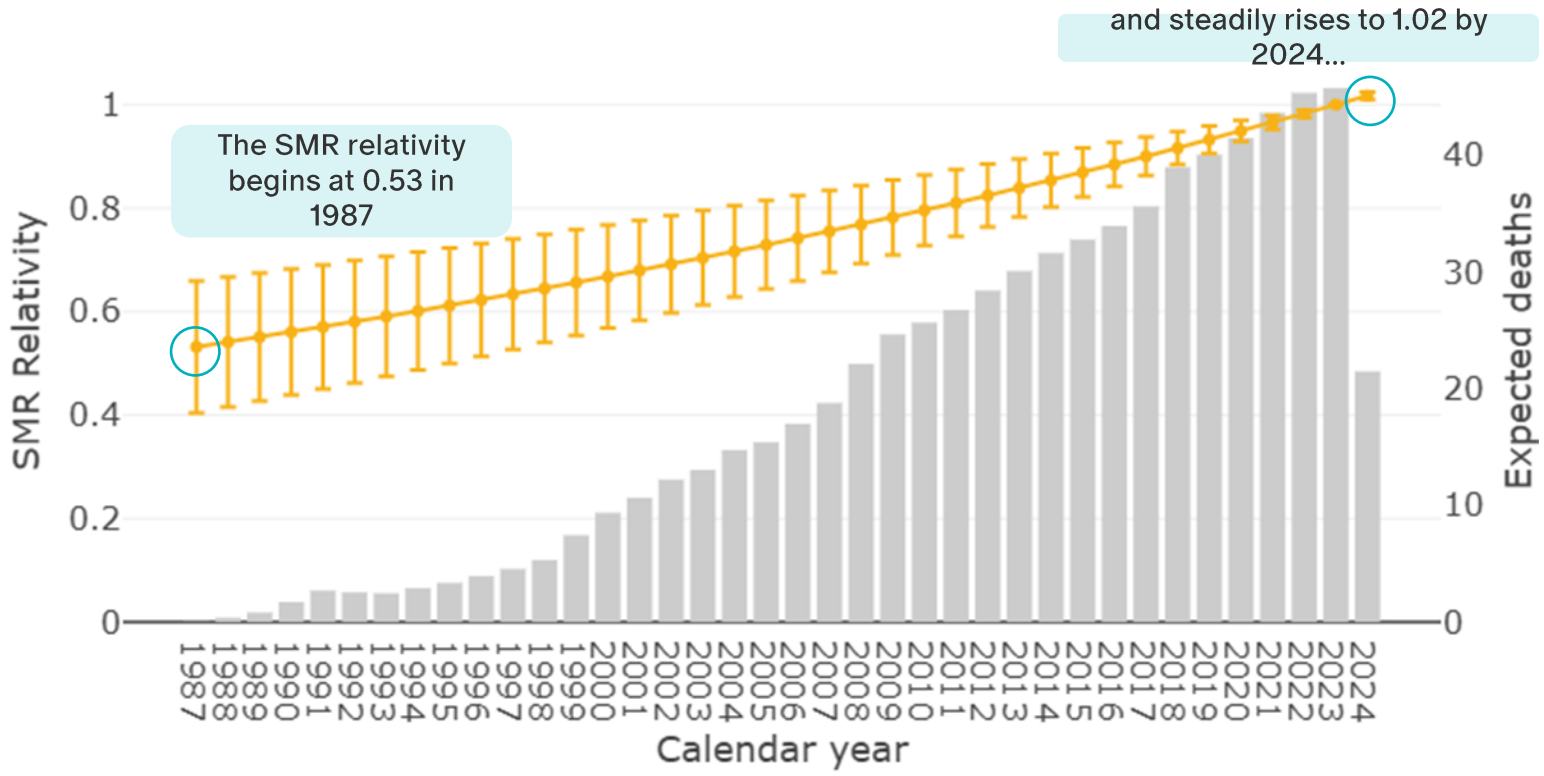
Calendar Year

TBI



A **clear, steady upward** trend is observed in excess mortality risk across the study period, spanning from the late 1980s to the early 2020s.

Suggests that mortality improvements within this cohort **lagged behind the general population**.

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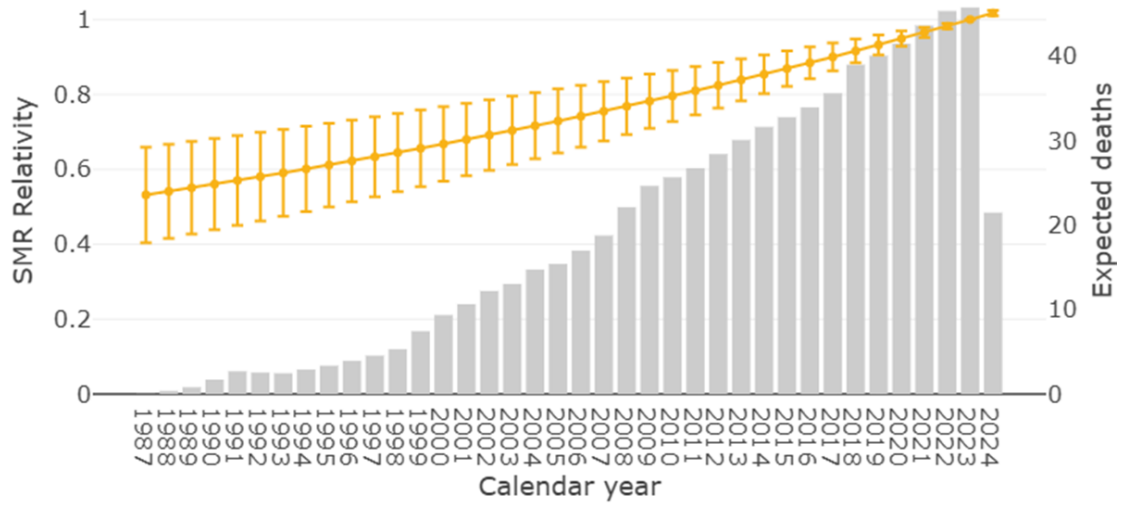
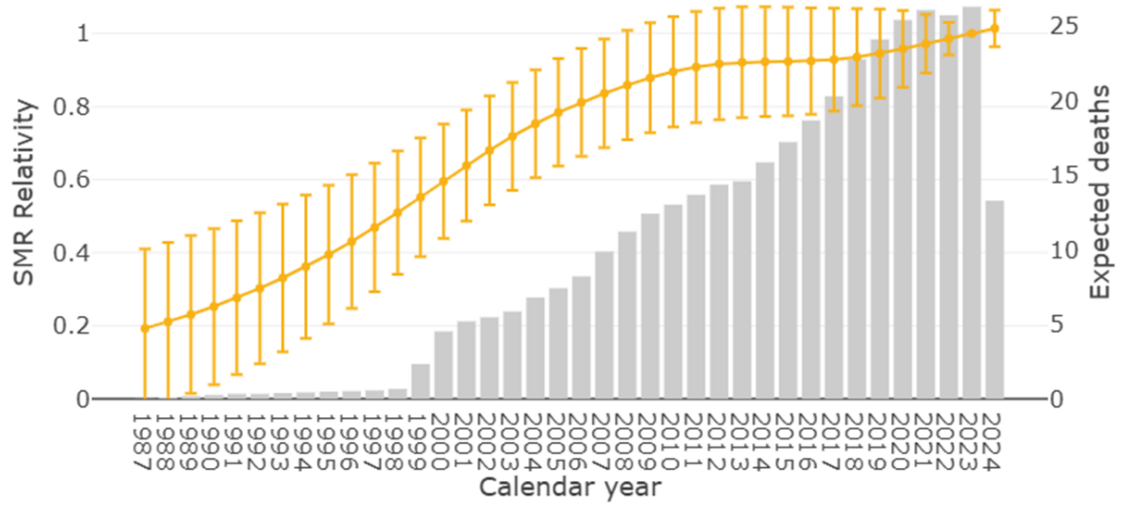
Calendar Year

TBI



SCI



A **clear, steady upward** trend is observed in excess mortality risk across the study period, spanning from the late 1980s to the early 2020s.

Suggests that mortality improvements within this cohort **lagged behind the general population**.

For SCI, we note that although the early rise appears steep, it occurs in a data-sparse period and levels into a more gradual upward trend from the 2000s onward

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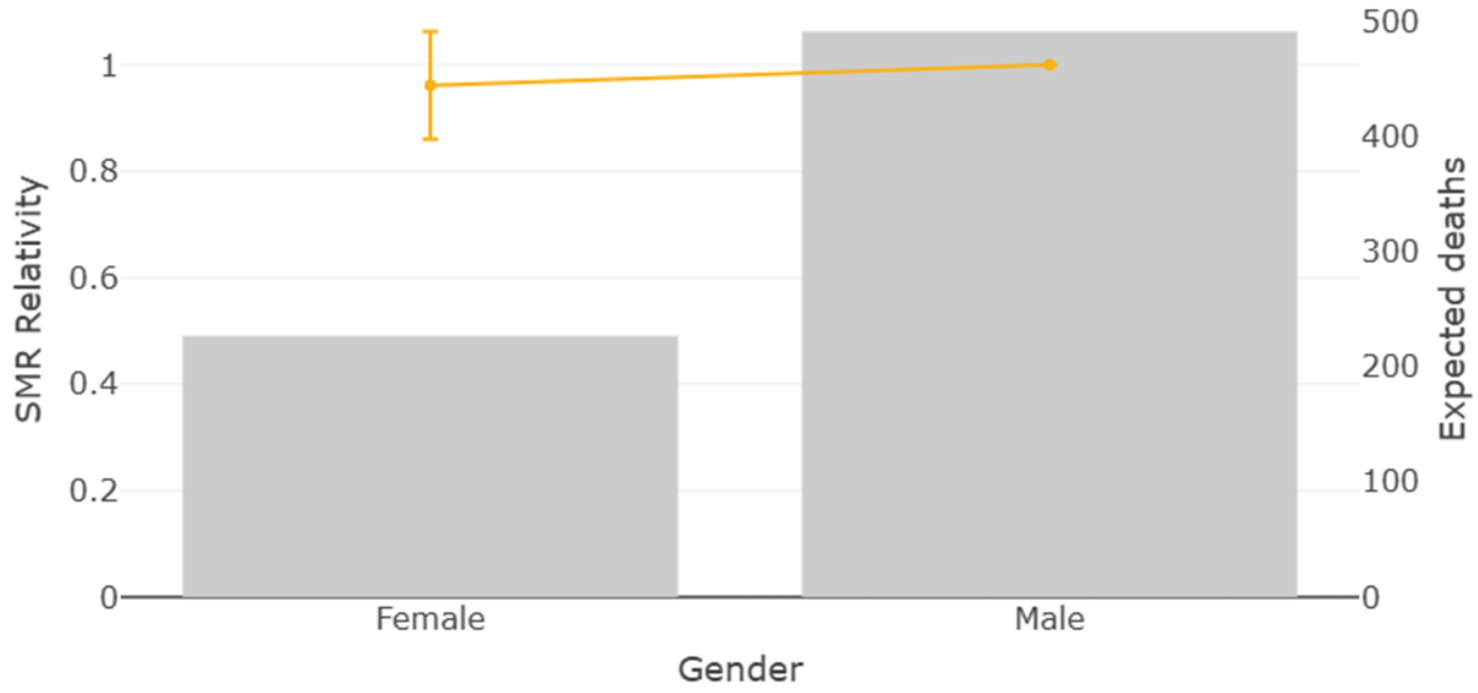
Gender

TBI



For TBI, females are associated with a slightly lower excess mortality risk compared to males.
However difference is not statistically significant.

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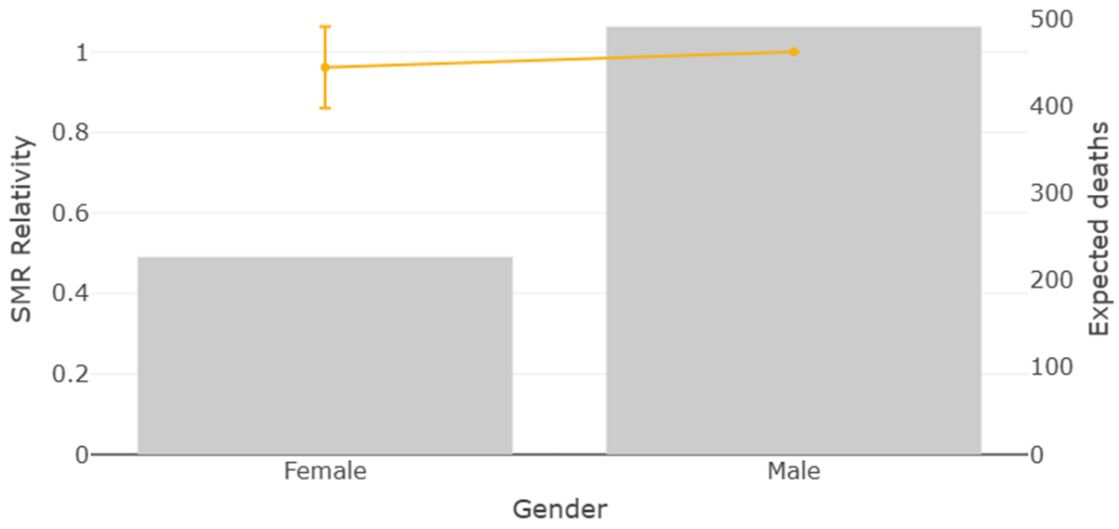
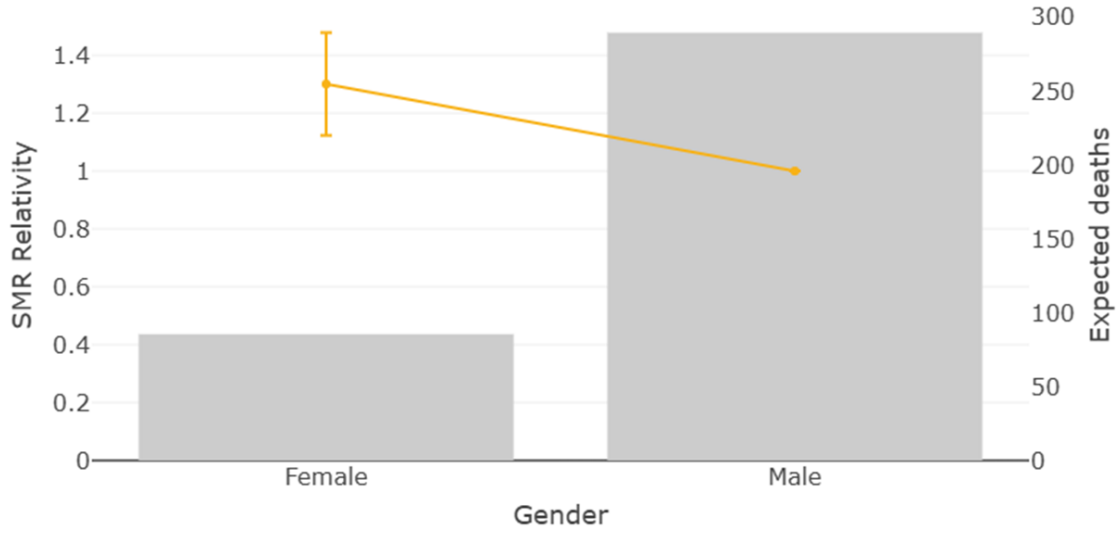
Gender

TBI



SCI

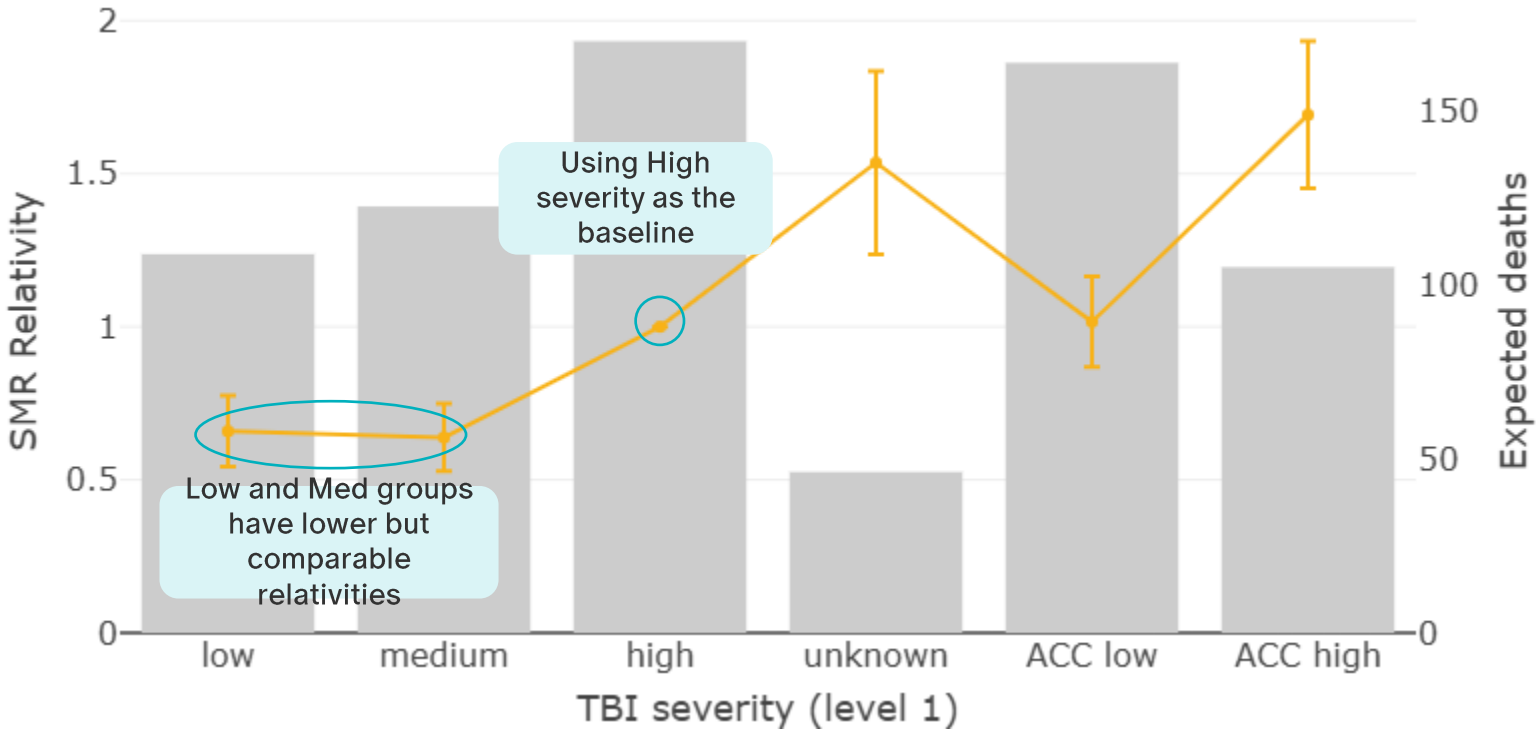


For TBI, females are associated with a slightly lower excess mortality risk compared to males.
However difference is not statistically significant.

For SCI, females are associated with a higher excess mortality risk compared to males.
Confidence interval suggests the difference is statistically significant.

Injury severity group level 1

TBI



SMR increases with TBI severity, showing clear differences across categories

Injury severity reflects each scheme's **latest view** of the participant's condition, and historical changes in severity were not available for analysis.

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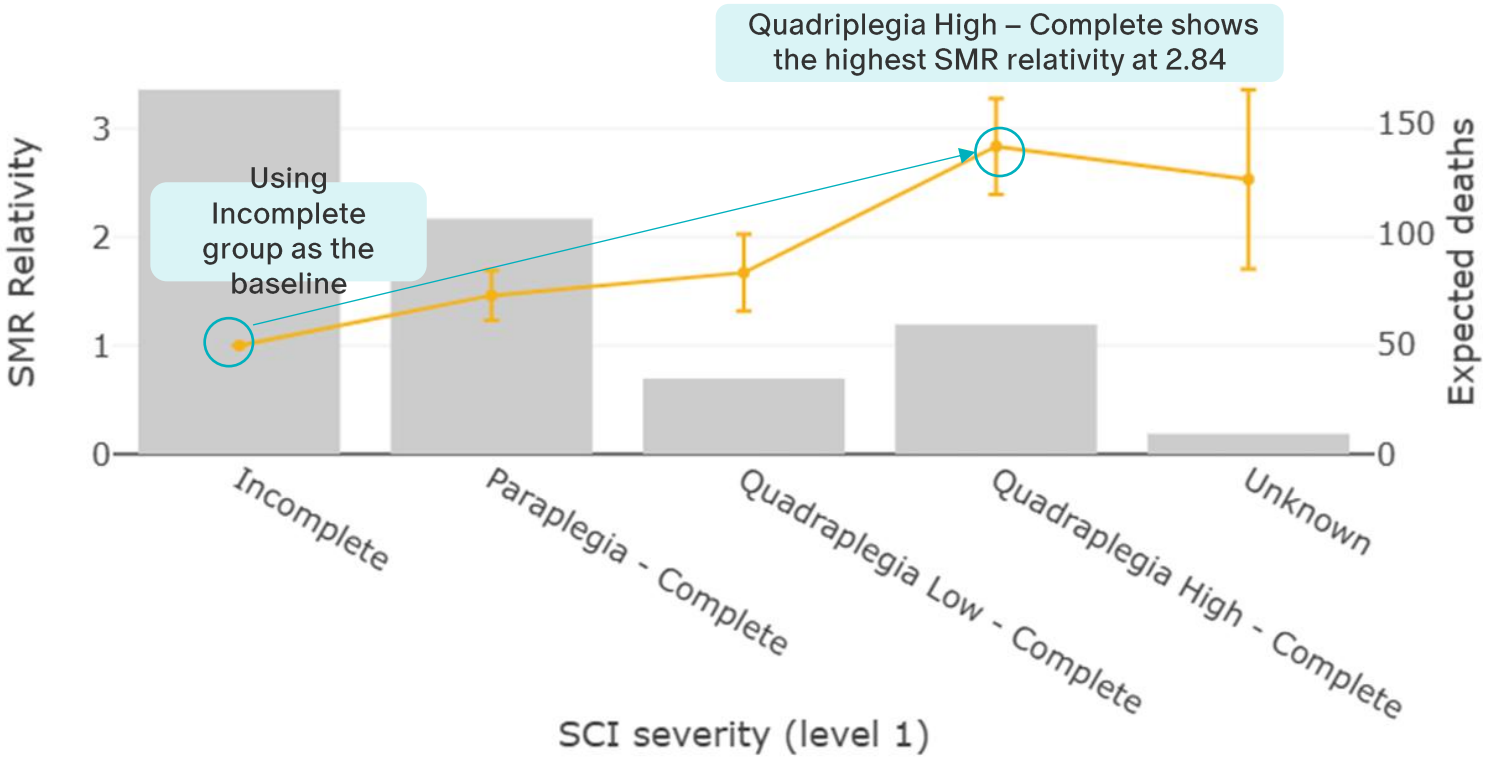
Injury severity group level 1

SCI



SMR increases with SCI severity, showing a clear gradient across categories

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Injury severity group level 2

TBI

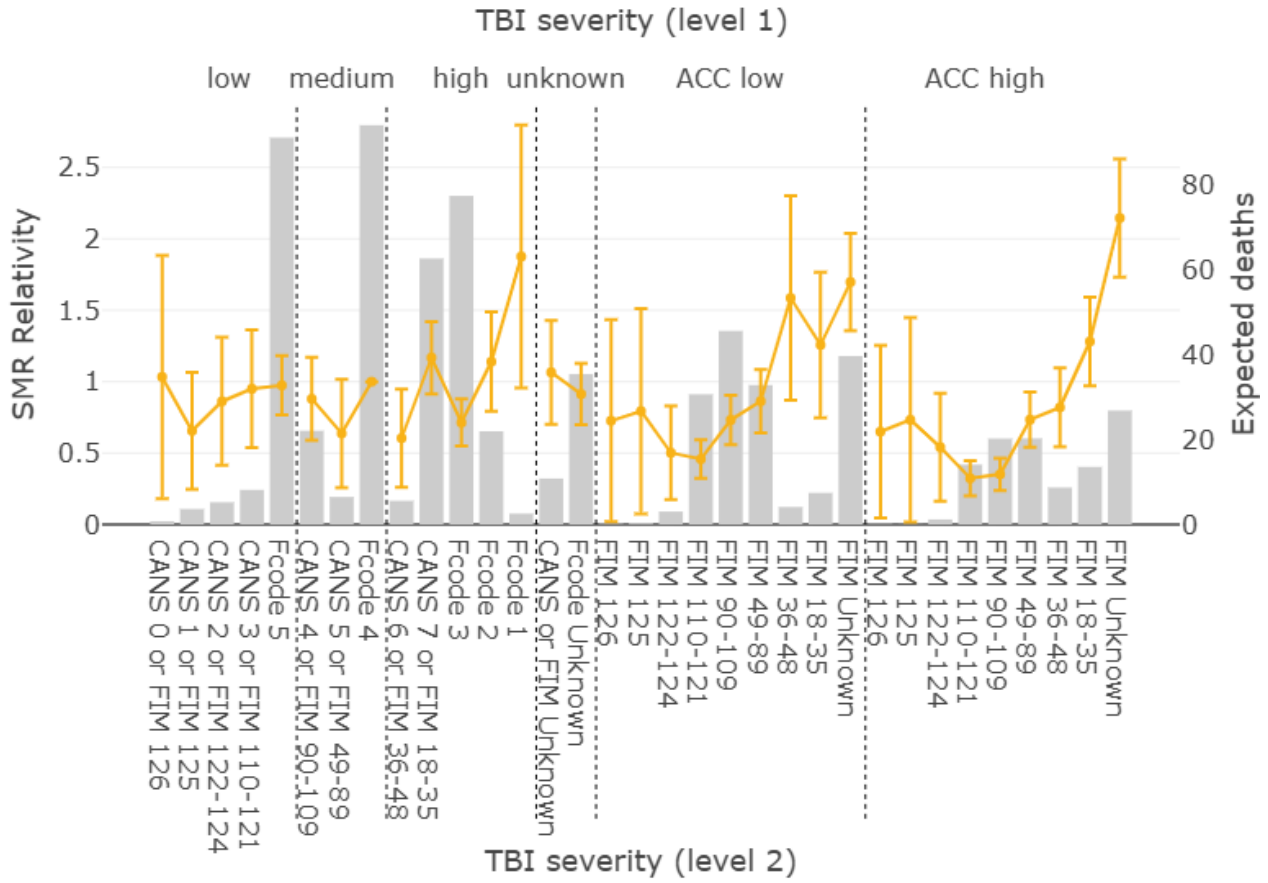
The hierarchical model refines the SMR estimates using **more detailed injury classifications**: CANS/FIM (ACC and other schemes) and Fcodes (TAC).

These act as **multiplicative adjustments** on top of the base (level 1) model.

Values **above** 1.0 Indicate **higher** mortality risk within the Level 1 category

Values **below** 1.0 Indicate **lower** mortality risk within the Level 1 category

Relativities generally **increase** with **higher functional impairment**.



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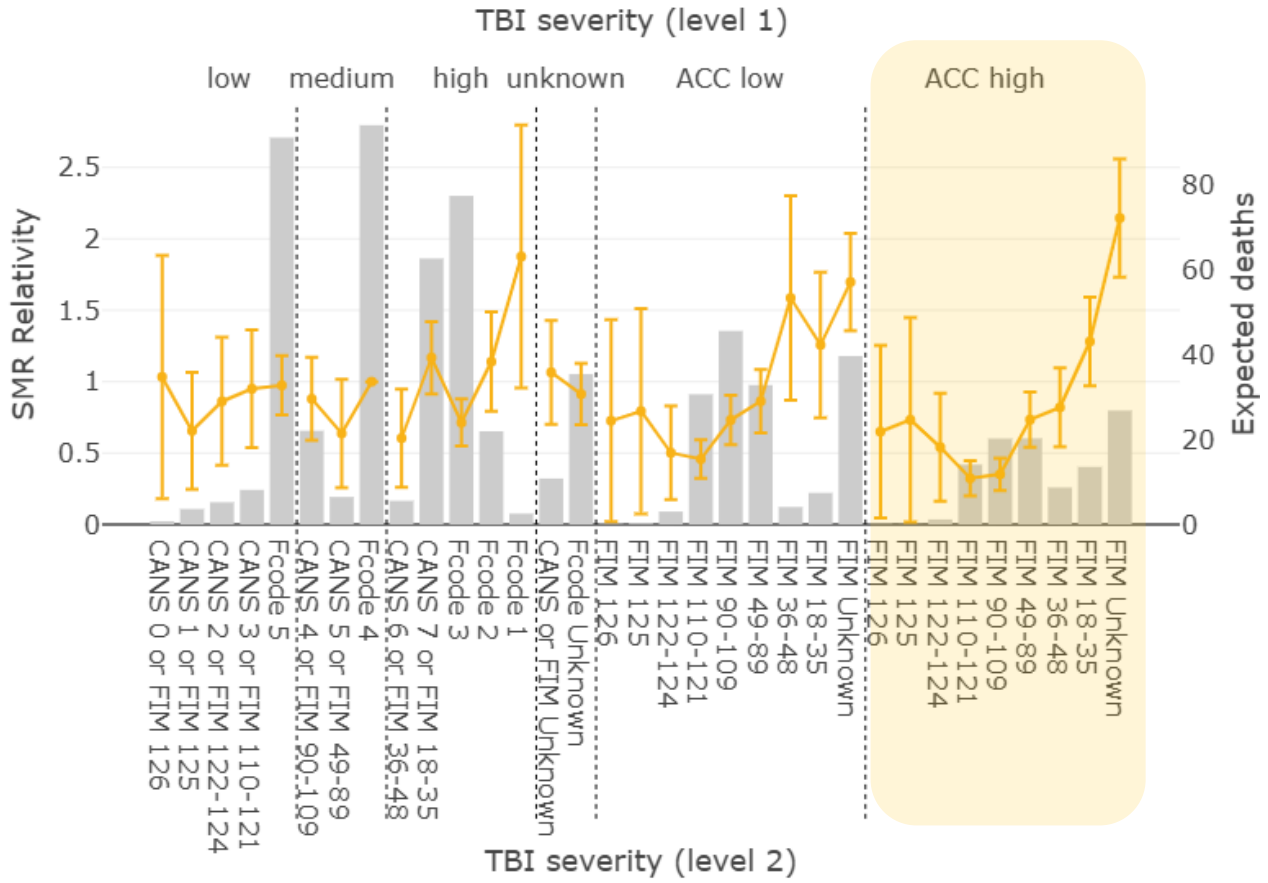
Injury severity group level 2

TBI

Within the **ACC high-severity group**, a clear upward gradient in mortality risk appears as FIM score declines

For the **highest FIM scores**, estimates are highly uncertain, and the model penalises effects towards zero due to limited data.

In these cases, **small manual adjustments** are applied to preserve a consistent monotonic progression, consistent with clinical expectation.



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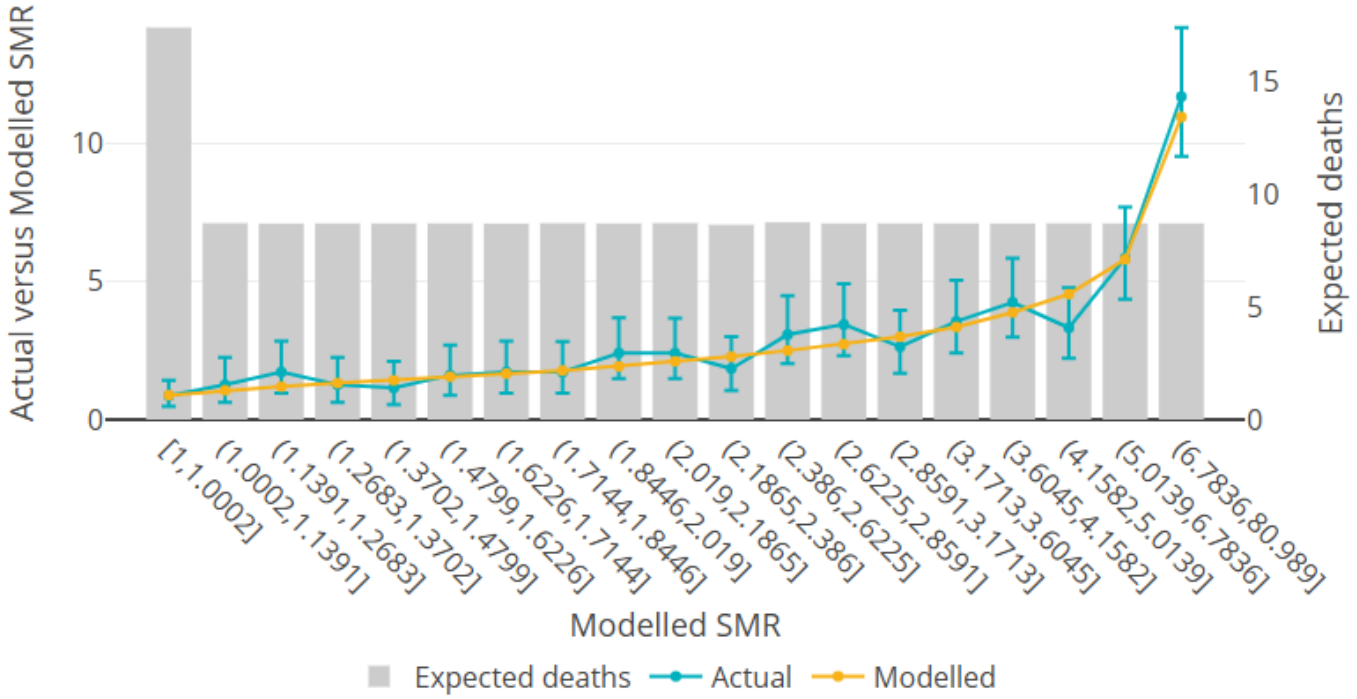
Goodness-of-Fit

To evaluate how well the refined model structure captures the observed mortality patterns, **goodness-of-fit analyses** were conducted on a test data set comprising 30% of the data.

TBI



Modelled SMR is represented by the yellow line

Observed SMR is represented by the blue line

Overall, the refined models appear **well-calibrated**, with the modelled SMR closely aligning with the observed SMR

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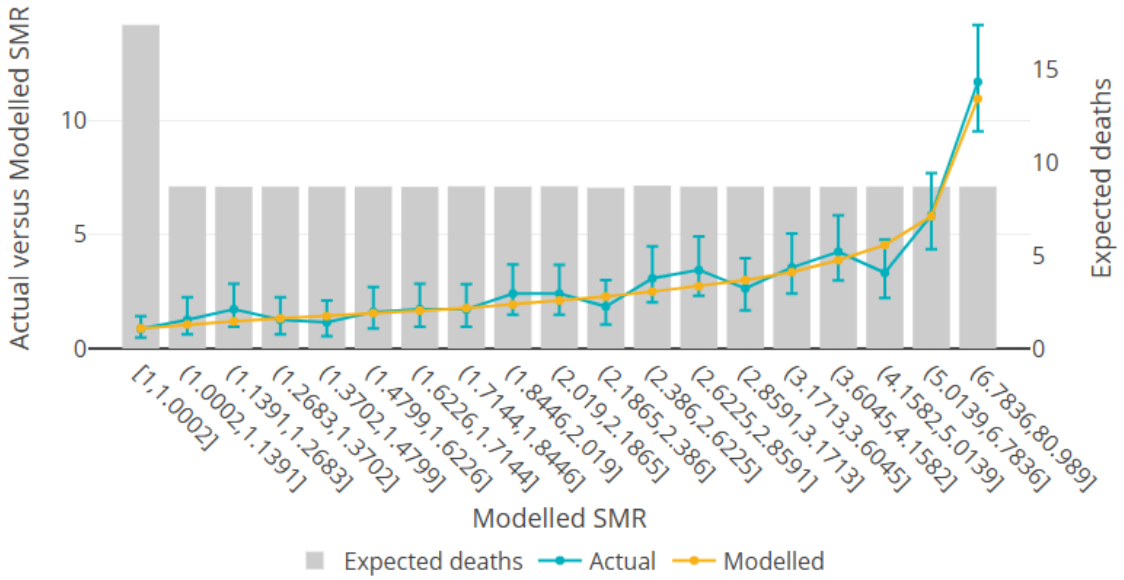

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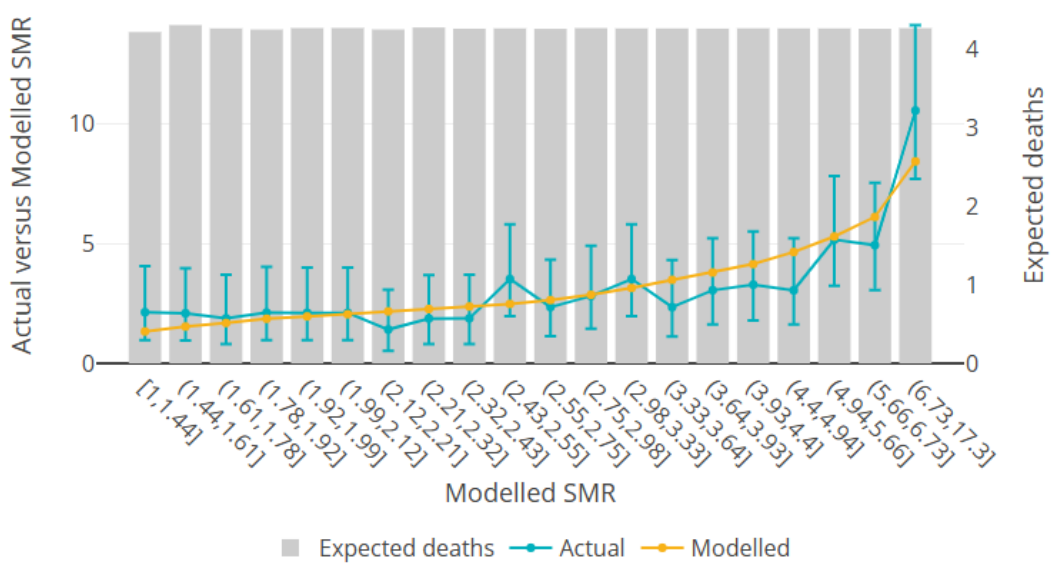

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Other Predictors

Model Validation

Prior to finalising this specification, the model structure was validated using 70/30 train-test split

Assessment on test set performance

Actual-vs-modelled plots across key dimensions were used to confirm model adequately captured observed mortality patterns

Alternative specifications and covariates

Models using attained age instead of age at injury, and those including gender interactions, were trialled but not adopted due to counter-intuitive shapes or limited improvement in fit.

Consideration of alternative factors

Further examinations of factors revealed some residual patterns

Geographic location

Lower than expected mortality in metropolitan areas for SCI

Socio-economic status

Lower than modelled mortality in the most advantaged socio-economic decile

Indigenous status

Higher relative mortality for Indigenous participants (particularly in SCI)

Final Selected Model

While noteworthy, these effects were subject to limited data and were therefore not incorporated into the final specification

The chosen model was judged to provide the best balance between interpretability, robustness and applicability for scheme valuations.

Sensitivity Testing

Several sensitivity analyses were conducted to assess **the robustness** of the SMR modelling results

Choice of population life tables	**National ABS life tables:** Replacing the state-specific tables for Australia with the national Australian life tables.
	AGA life tables: Replacing the state-specific tables for Australia with the AGA Australian Life Tables.
Exclusion of NZ ACC data	Assessing the impact of focusing solely on the Australian schemes
Time Period	Restricting the analysis to data up to 2019, i.e. excluding the COVID period.

The sensitivity analyses revealed that while the overall SMR level could change minimally depending on the scenario, **the core patterns of SMR relativities** across covariates like age, duration, calendar year and severity were **consistent** with the main analysis.

Key Takeaways

This study provides the **first trans-Tasman evidence** based on mortality outcomes for catastrophically injured participants in injury and disability schemes

By pooling data across nine schemes, we created a large, contemporary dataset.

This enables **more reliable analysis than any scheme could achieve alone**

The analysis highlights **clear variation** by age at injury, duration since injury, severity, and gender. This is in line with international research.

Results show that while mortality has improved for the general population, **improvements have not been mirrored for TBI and SCI cohorts**

The outputs are **robust mortality benchmarks** that can be directly applied in actuarial valuations, supporting consistent and scheme-relevant assumptions.

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The Actuaries Institute is the peak professional body for Actuaries in Australia. The Institute provides expert comment on public policy issues where there is uncertainty of future financial outcomes.

Actuaries have a reputation for a high level of technical financial expertise and integrity. They apply their analytical and risk management expertise to allocate resources efficiently, identify and mitigate emerging risks and to help maintain system integrity across multiple segments of the financial and other sectors. This unrivalled expertise enables the profession to comment on a wide range of issues including life, general and health insurance, climate change, superannuation and retirement income policy, enterprise risk management and prudential regulation, the digital economy, finance and investment and wider health issues.

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Thank you

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