Balancing Accuracy and Wearability: Sensor Configuration Strategies for Real-World Near-Fall Detection

HEALTHY WORKPLACES SUMMIT 2025
SAFE AND HEALTHY WORK IN THE DIGITAL AGE

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Healthy Workplaces

Prevention of tripping, slipping and falling accidents – why?

Frequency

One in five accidents at work is a trip, slip or fall accident (STF)
2024: Total 164.912. Fatal 10.
Pensions 2.374

164.912

Impacts

From painful injuries to long-term damage

Strains
Contusions
Fractures

Economy

Total 2024: €292,26 million
Rehab. costs: €290,20 million

292.26 M. €

Deutsche Gesetzliche Unfallversicherung e.V.; (German Social Accident Insurance, DGUV), "Statistik Arbeitsunfallgeschehen 2024," Deutsche, Gesetzliche Unfallversicherung e.V., Berlin, 2025.

Hierarchy of Prevention Measures and Role of AI

Slip, trip and fall prevention follows the established hierarchy of prevention measures, addressing STF risks at system level before targeting individual workers.

1

Substitution & Technical Measures

Safer flooring, improved walking surfaces and elimination of known slip and trip hazards in high-risk areas remain the primary prevention strategy.

2

Organisational Measures

Route and working hours planning, hazard recognition training and integration of perturbation-based training into existing prevention programmes.

3

Personal Measures

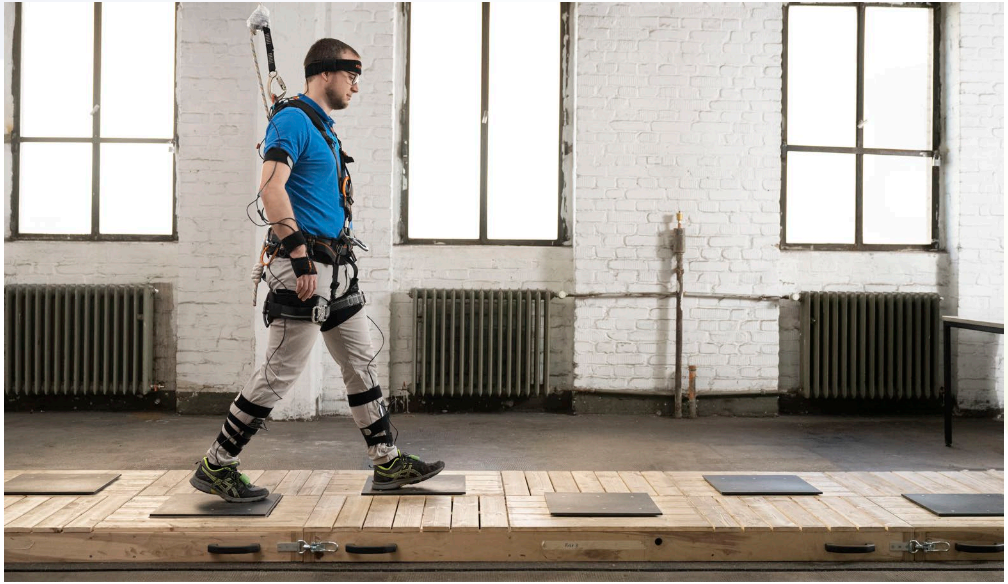
Appropriate footwear, individual training and wearable sensors for near-fall detection as additional support, not substitutes for upstream prevention.

4

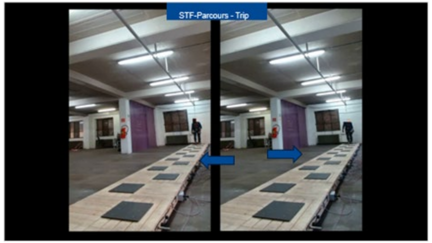
AI-Based Detection

OSH-driven tools that identify critical situations and inform collective preventive actions at workplace level, including targeted improvements of routes, surfaces and task design.

SLIP, TRIP, MISSTEP PARCOURS



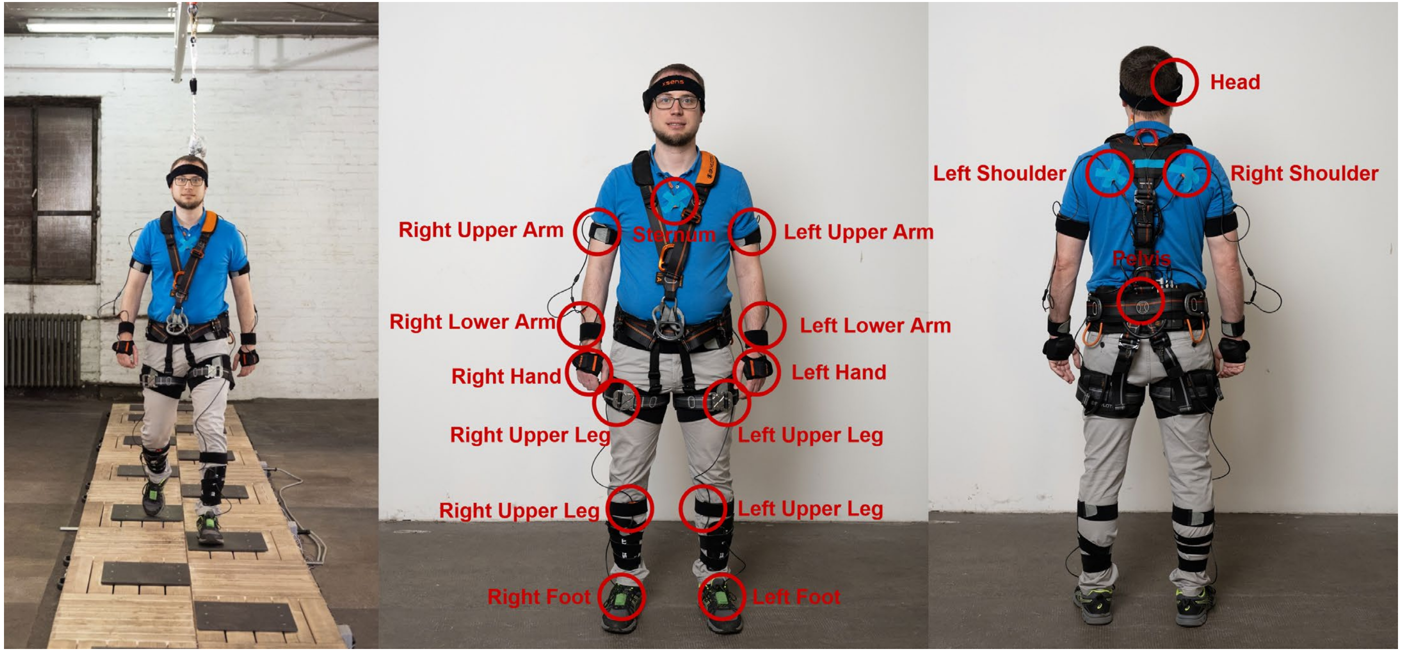
Assessment of severity of stumbling before and after training



Slip

Misstep

Full-body measurement sensors



Schneider, M., Reich, K., Hartmann, U., Hermanns, I., Kaufmann, M., Kluge, A., ... & Ellegast, R. (2024). Acquisition of Data on Kinematic Responses to Unpredictable Gait Perturbations: Collection and Quality Assurance of Data for Use in Machine Learning Algorithms for (Near-) Fall Detection. *Sensors (Basel, Switzerland)*, *24*(16), 5381.

Ellegast, R., Hartmann, U., Karamanidis, K., Kluge, A., Kaufmann, M., Krugmann, L., Schneider, M., Zimmermann, J., Lungfiel, A., Bohlscheid, A., Nickel, P., Schiefer, C., Hermanns-Truxius, I., Werth, J., & Weber, A.; "Final Report of the ENTRAPon Project: Development of Additional Training Ele-ments for the Prevention of Slip, Trip and Fall Accidents Supported by Virtual Reality and Mechanical Perturbation Training";

Worker and Workers' Council Involvement, Ethics and Human-Centred Study Design

Voluntary Participation

Steelworkers and parcel delivery workers recruited as active employees, fully informed in writing about study aims, procedures and risks.

Continuous Collaboration

Close partnership with company partners and ongoing involvement of workers' councils and OSH representatives in planning and risk assessment.

Real-world scenarios

Scenarios and walking speeds based on accident reports and real-world scenarios to ensure realism and acceptable workload

Transparent Communication

- Written informed consent from all participants
- Clear separation of research data from performance appraisal
- Regular feedback opportunities for participants and councils

Data Protection by Design

- GDPR compliant pseudonymisation protocols
- Restricted access to raw data
- Only aggregated results reported to companies and councils

PrevFall Dataset

110 Subjects

50% HKM — Steelworker

50% DHL — Parcel delivery

~1 MILLION

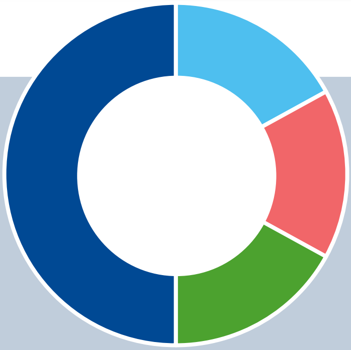
kinematic data points

~500 K

Tripping, slipping and missteps Data points

~500 K

Baseline walking data points



Class Balance

17% Slip

16% Trip

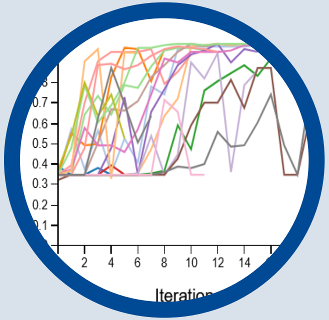
17% Misstep

50% Base

Schneider, M., Reich, K., Hartmann, U., Hermanns, I., Kaufmann, M., Kluge, A., ... & Ellegast, R. (2024). Acquisition of Data on Kinematic Responses to Unpredictable Gait Perturbations: Collection and Quality Assurance of Data for Use in Machine Learning Algorithms for (Near-) Fall Detection. *Sensors (Basel, Switzerland)*, *24*(16), 5381.

Automatic detection of near falls using AI

Neural Architecture Search

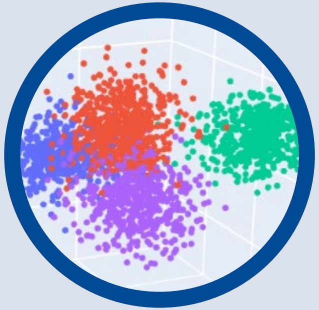


DeepConvLSTM
F1 91.95

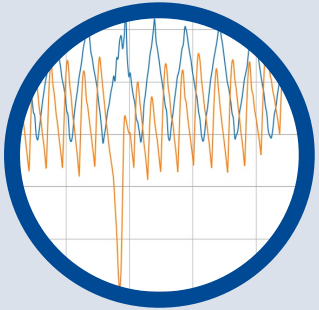
CNN
F1 96.22

ResNet
F1 95.31

InceptionTime
F1 96.32



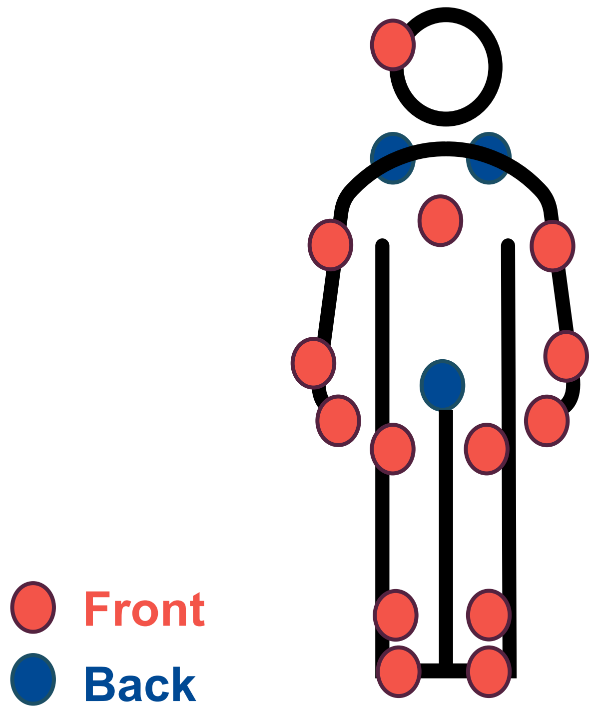
LDA demonstrates class separability



No differences in linear correlation between and within classes

Schneider, M., Seeser-Reich, K., Fiedler, A., & Frese, U. (2025). Enhancing Slip, Trip, and Fall Prevention: Real-World Near-Fall Detection with Advanced Machine Learning Technique. *Sensors (Basel, Switzerland)*, *25*(5), 1468.

Objective: Minimal sensor configurations for STF detection



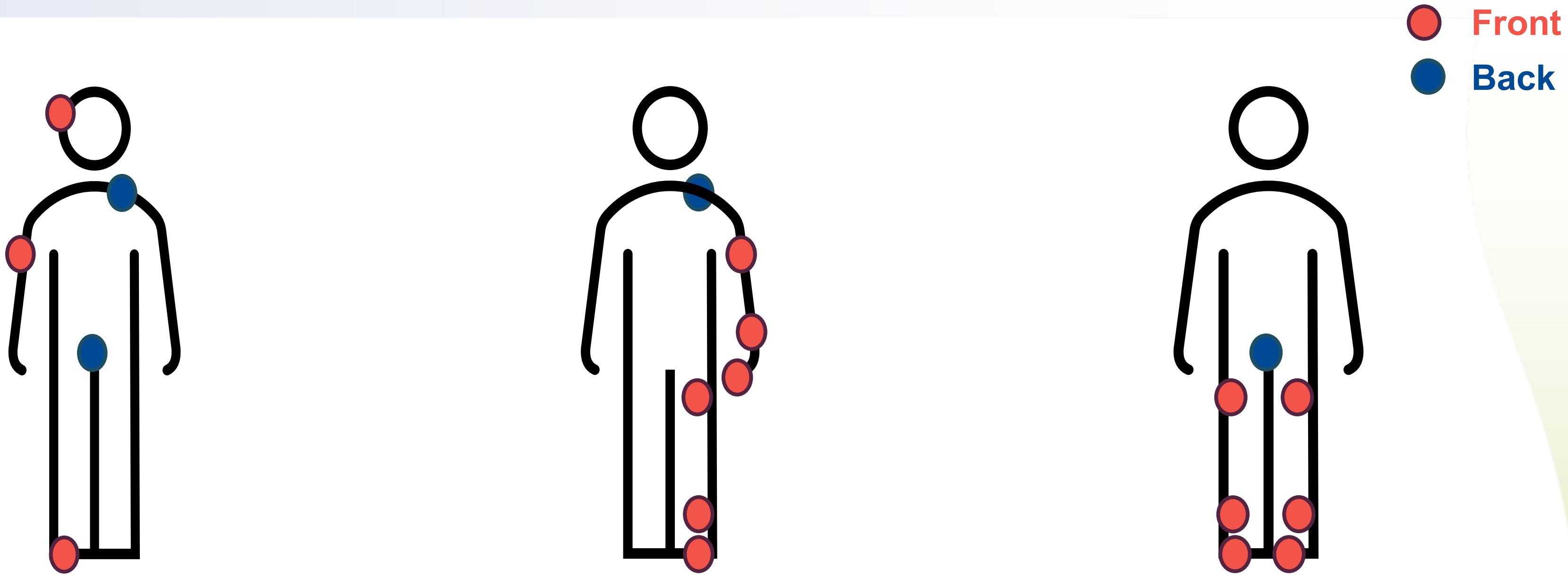
Complete sensor system achieves good results, but:

- expensive
- computationally intensive
- restricts movement in everyday working life
- time-consuming to set up

Three strategies for sensor reduction:

I. Optimised coverage of anatomical regions
II. Unilateral reduction
III. Optimised coverage of critical regions

Three strategies for sensor reduction



Hypothesis:
One representative sensor per region suffices to capture essential motion patterns

Hypothesis:
One body side contains sufficient information for accurate classification.

Hypothesis:
Sensors on arms, head, and chest are less informative and can be removed.

Brief overview results

Strategie	# Sensoren	Sensorpositionen	Acc. (%)	Weighted F1-Score	FPR (%) vs. Full-Body*
I - Optimised coverage of anatomical regions	4	Head, Left Shoulder, Pelvis, Right Foot	86.97	0.910	10.59 (–32.33 %)
	3	Left Shoulder, Pelvis, Right Foot	83.73	0.880	—
	2	Pelvis, Right Foot	77.39	0.814	—
II - Single-sided reduction	4	Left Shoulder, Left Upper Arm, Left Forearm, Left Foot	82.94	0.871	15.68 (+0.19 %)
	3	Left Shoulder, Left Upper Arm, Left Foot	81.69	0.858	—
	2	Left Shoulder, Left Forearm	81.69	0.857	—
III -Optimised coverage of critical regions	4	Left Foot, Right Foot, Left Lower LegL, Right Lower Leg	84.51	0.889	1.52 (–90.29 %)
	3	Left Lower Leg, Right Lower Leg, Left Foot	82.78	0.874	—
	2	Left Lower Leg, Left Foot	84.59	0.889	—

Brief overview results – Key findings

Strategy

Best trade-off: Strategy III
(Optimised coverage of critical regions)
with only 2 sensors

Networks

DeepConvLSTM and
CNNs performed best under
minimal conditions

FPR

Clear reduction in false
positives, especially when
excluding upper-body sensors

Field study

The findings of this study
indicate that minimal sensor configuration
are ready to be validated in the field

Shaping Digital Tools Through OSH Principles

Prevention First
Prioritising systemic improvements over individual monitoring

Proportionality
Ensuring monitoring measures are appropriate and justified

Transparency
Clear communication about data use and system operation

Worker Consent
Voluntary participation with full informed agreement

Building Trust Through Design: By embedding OSH principles into AI systems for near-fall detection, organisations can strengthen trust, support ergonomics and psychosocial wellbeing, and contribute to safer and more sustainable digital workplaces.

Thank you for your attention

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