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# Self-reported pedestrian falls in 15 countries worldwide

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ABSTRACT

*Background:* Many factors are associated with pedestrian injuries and accidents. If a pedestrian is injured in an outdoor public space, we are talking about a "pedestrian fall". Pedestrian falls are a more common cause of pedestrian injuries than traffic crashes but have received less attention and the literature on this topic is scarce.
*Aims and methods:* The aim of this work is to describe at a general level the prevalence and consequences of pedestrian falls and injuries, to make international comparisons of pedestrian falls and to identify risk factors and not least to examine the relationships between the prevalence of falls and pedestrian risk behaviour. A total of 6,373 participants from 15 different countries were recruited to take part in this study. To collect data a questionnaire was used. To cover the risky behaviour of pedestrians we used a short version of Pedestrians Behaviour Scale (PBS). In order to identify groups of countries with a similar pedestrian transport situation, a hierarchical

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cluster analysis was performed. The analysis produced four groups of countries based on pedestrians' safety level, popularity of walking and GDP.
*Results and conclusions:* As for the results, we can conclude that young people and older people are more frequently involved in falls and that women report more frequent involvement in falls than males. However, the risk of getting injured in a fall is not higher than that of men. Frequent walking is associated with a lower risk of falling while walking. In contrast to this, physical activity increases such risk. The prevalence of falls and injuries seems to be weakly related to pedestrians' risky behaviour, thus other factors such as safety infrastructure probably play an important role.

## 1. Introduction

Walking is a natural part of everyday life for the majority of the world's population, and thus has an important role in transport systems, infrastructure building, and public health development, as regular walking is thought to benefit mental and physical health, as well as reducing the risk of chronic disease and contribute to a sustainable and ecological way of life (Cubukcu, 2013; Lee & Moudon, 2006; Lee & Buchner, 2008). Despite the great importance of walking, it is often forgotten that pedestrians are the most vulnerable road users and, as persons involved in accidents, are much more susceptible to injuries of varying severity. Statistics show that in the European Union, pedestrians accounted for approximately 20 % of all road accident casualties between 2010 and 2020 (European Parliament, 2021).

Many factors are associated with pedestrian injuries and accidents. Pedestrians expose themselves to an increased risk of injury or accident by erroneous behaviours such as failing to yield the right of way, ignoring traffic signs and signals, walking outside a pedestrian crossing or walking in an intoxicated state (Clifton et al., 2009; Ulfarsson et al., 2010). A significant contributor to current risk behaviours is the use of phones while walking. These pedestrians are reported to have a higher prevalence of risk behaviours than pedestrians without electronic devices. In particular, errors are manifested in the form of lower alertness, longer reaction times, and reduced ability to perceive surroundings (Horberry et al., 2019; Jiang et al., 2018; Thompson et al., 2013), which increases the risk of being involved in a traffic accident.

Pedestrian injuries often occur when pedestrians unexpectedly run into the roadway or emerge from between parked cars (Ulfarsson et al., 2010), which is a particular problem for children. As cognitive processes in children are different from adults, their vulnerability to traffic is significantly higher. There are a number of factors that influence safe behaviour in children, and the development of cognitive processes and abilities, as well as the development of perception, are considered to be particularly important. Thus, a child of younger school age is unable to adequately assess the distance and speed of road users, and also has difficulty dividing and focusing attention on important elements, processing information and making appropriate decisions (Schwebel et al., 2012). Children are thus more prone to errors, increasing the risk of a traffic accident. It has been shown that children under the age of 12 are twice as error-prone as people aged 17 and above (Ulfarsson et al., 2010). Pedestrians aged 65 years and over are considered to be another at-risk group, who are significantly more at risk of fatal injury. Older pedestrians are often associated with a decline in perceptual and cognitive function, slower reactions and more frequent use of this mode of transport, which is however also associated with longer time in traffic due to slower movement, putting them at increased risk of an accident (Clifton et al., 2009; S. Kim & Ulfarsson, 2019). Gender emerges as another significant factor, as men are more likely to make errors as pedestrians and at the same time are more likely to be injured (Clifton et al., 2009; Ulfarsson et al., 2010). External factors such as time of day coupled with visibility in the dark also contribute to pedestrian injuries and accidents. It has been shown that after dark there is an increased likelihood of injury (Clifton et al., 2009; Ulfarsson et al., 2010).

Infrastructure also plays an important role in pedestrian safety and behaviour. Therefore, the choices made in terms of urban planning and design have consequences and impact the way pedestrians perceive and utilize public spaces, as well as their decision-making process when crossing urban roads. This presents a challenge for planners and road engineers, as they must consider all users when designing public spaces, emphasizing the importance of considering the environment (Granié et al., 2014). Earlier findings demonstrated that the level of inconvenience experienced by pedestrians in urban traffic due to transgressive behaviour was entirely influenced by the effectiveness of the traffic safety climate. As pedestrians' perceived inconvenience grows, there is a correlation indicating that they view the traffic safety climate as emotionally demanding and less efficient. The more frequently pedestrians encounter situations such as a cluttered sidewalk or the absence of a sidewalk, the more likely they are to perceive city traffic as chaotic, less "smooth-flowing," and less safe, with a sense that circumstances are left to chance. This finding highlights the significance of infrastructure development, particularly the construction of pedestrian-friendly infrastructure. When pedestrians perceive inconvenience in participating in city traffic, they are more likely to attribute it to the inefficiency of the traffic system. As pedestrians perceive the functionality of urban traffic as less safe and less harmonious, they tend to consciously disregard legal rules or unintentionally make errors without intending to violate the law (Xu et al., 2018).

Crossing a road against the signal or outside of a designated crosswalk increases the risk of getting injured. Such behaviours might be more prevalent in areas where the pedestrian infrastructure is insufficient or fails to adequately cater to the needs of pedestrians (Clifton et al., 2009). Results from Greek city showed that pedestrians who exhibited the highest level of adherence to traffic laws were observed primarily on main arterials, whereas the lowest level of compliance was seen on local streets. The combination of low vehicular traffic volume and issues related to the maintenance and accessibility of pedestrian infrastructure encourages pedestrians to walk on the roadway, disregarding potential safety concerns (Galanis et al., 2017).

This leads to the fact that the local surroundings and road infrastructure significantly contribute to the occurrence of road accidents (Flahaut, 2004). For instance, the availability of public transport and the number of public transport stops have been shown to correlate with the number of traffic accidents (Pljakić et al., 2022; Su et al., 2021). In places with good access to public transport and city centres, injuries occur with less serious consequences, but also these are places where collisions are more likely to occur (Clifton et al., 2009). Crashes also occur most frequently in residential and commercial areas, especially away from intersections, such as parking lots or driveways (Kim et al., 2008). While urban areas have a greater likelihood of experiencing pedestrian accidents due to their higher traffic density, rural areas are significantly more prone to severe or fatal pedestrian accidents (Clifton et al., 2009; Zegeer & Bushell, 2012).

Regarding infrastructure, an examination of safety within a shared environment accommodating various modes of transportation, including bicycles, or e-scooters, is pertinent. Nevertheless, scant empirical data currently exists to quantify the incidence of collisions and resultant injuries arising from such intermodal interactions. According to Mesimäki and Luoma (2021), the probability of a near-collision involving a cyclist and a pedestrian is 50 times higher than that of an actual collision. This underscores the prevalence of close calls that may not result in direct physical harm but contribute to the overall risk perception. Findings from another study align with this trend, suggesting that pedestrian injuries in collisions with cyclists are comparatively less frequent than injuries sustained in collisions with motor vehicles (O'Hern & Oxley, 2019). From previous findings, we can highlight that although there is a low number of direct collisions between cyclists and pedestrians, the majority occur off-road, particularly on shared pathways or pavements designated for pedestrians or cyclists (De Rome et al., 2014; Poulos et al., 2015).

Moving to the realm of e-scooters, even less data on accidents in the context of infrastructure is available. A study from California shows that 11 % of incidents between pedestrians and e-scooters occurred on pavements (Bloom et al., 2021). The incidence rate of injuries exhibits variability across diverse investigations. However, in the examination of treated injuries, a spectrum is discerned, spanning approximately 3 % to 8 % of cases in which an electric scooter is implicated as a contributing factor to the injury (Bloom et al., 2021; Ishmael et al., 2020; Trivedi et al., 2019). The Israel Trauma Registry's comprehensive study on e-bikes and motorized scooters demonstrates a substantial increase in the number of hospitalizations resulting from accidents, with 8 % of injuries involving pedestrians. Among pedestrians, emphasizing the vulnerability of different age groups, 42 % were children and 33 % were seniors aged 60 and above (Siman-Tov et al., 2017).

According to the European Road Safety Observatory (European Commission, 2020), a pedestrian is a person on foot, including occupants or persons pushing or pulling a child's carriage, an invalid chair, or any other small vehicle without an engine. When pedestrian fatalities or injuries are being referred to, unilateral pedestrian crashes (e.g. pedestrian falls) are excluded. The definition of an injury road collision in the EU concerns an incident on a public road that involves at least one moving vehicle and at least one casualty (person injured or killed). Pedestrian falls on a footway or a carriageway, even where they may be due to the poor quality of the sidewalk or in reaction to the activity of the user and without any impact on another road user, are not considered to be road casualties. Thus, single pedestrian falls are not reported in police statistics. The scope and problem of injuries resulting from pedestrian falls in traffic are overlooked. The number of injuries, and even deaths, following a pedestrian fall in traffic without a motorised vehicle being involved is surprisingly high and represents a significant cost to society. As a result, data referring to injuries or possible deaths as a result of pedestrian falls are very scarce.

The places where pedestrians move are not only roads but also sidewalks, parks, squares, and many other public places where pedestrians can suffer injuries even without colliding with a vehicle. Thus, in line with Methorst et al. (2017), we adopt their redefinition of a pedestrian fall as follows: if a pedestrian is injured in an outdoor public space (apart from in a road accident), we are talking about a "pedestrian fall". Pedestrian falls are a more common cause of pedestrian injuries than traffic crashes but have received less attention (Schepers et al., 2017).

With respect to this paper and the countries under study (15 countries), only one country (Finland) has relevant data available. Besides Finland, to estimate the scope of the single pedestrian fall problem, we will use the cases of Sweden and the Netherlands, for which data are available. A study conducted by Berntman (2015) revealed that 13 % (34 out of 254) of all pedestrian deaths in traffic in Sweden that occurred over the period 2009–2013 were a result of pedestrian falls. Over the same five-year period 15,600 pedestrians who fell sustained serious injuries. This corresponds to about 3,150 pedestrians severely injured in falls every year, i.e. more than 30 times more pedestrians are injured in falls compared to collisions with a motorized vehicle. A study on single pedestrian falls in the Netherlands (Methorst, 2020) shows that over the period 1996 to 2017, 46 % (1,610 out of 3,526) of all pedestrian deaths in traffic in the Netherlands were pedestrian falls with no vehicle involved. The other study, conducted in Finland (Malin, Mesimäki, & Penttinen, 2022) shows that roughly 125,000 pedestrian falls resulting in injury occur annually in Finland. Approximately 75,000 (60 %) of these are winter slip-and-fall accidents. The risk of injury when walking is considerably higher than that of driving a passenger car, using public transport, or cycling when slip-and-fall accidents occurring in traffic environments are considered in risk calculations.

To sum up, among the overall population of road users who sustain injuries pedestrians involved in traffic accidents with other road users constitute a relatively small percentage, ranging from 2 % to 4 %. Conversely, a significantly larger proportion, ranging from 20 % to 60 %, is attributed to pedestrian injuries resulting from falls (Methorst et al., 2017). To better estimate the frequency of occurrence, it is particularly useful to monitor data from health organizations and supplement this with police road accident statistics (Oxley et al., 2018).

Many factors are involved in pedestrian crashes and injuries, both on the side of pedestrians and the traffic environment. Susceptibility to injury varies with the age of the pedestrian. Risk has been shown to increase in childhood and adolescence up to about age 19 and then decrease until age 50. At this age, the risk of falling while walking begins to increase significantly (Björnstig et al., 1997; Elvik & Bjørnskau, 2019). In most studies, women are more prone to falls (Björnstig et al., 1997; Elvik & Bjørnskau, 2019; Lai et al., 2009). Falls occur more frequently on damp and wet surfaces and thus falls are more frequent during the winter months (Elvik & Bjørnskau, 2019; Lai et al., 2009; Öberg, 2011). Statistics from Sweden show that falls occur mainly between November and April (Björnstig et al., 1997). Most falls occur on streets on sidewalks and curbs (Li et al., 2006; Naumann et al., 2011). In addition to age, gender, and weather, the area in which a pedestrian is located can also influence the occurrence of falls. A study from Boston showed that lower SES neighbourhoods experienced more frequent falls on sidewalks and curbs. It also showed that people from these areas use walking more purposefully as a mode of transportation than for the purpose of relaxation and recreation and have the highest representation of pedestrian falls (Li et al., 2014).

As mentioned earlier, few data map the frequency of occurrence and circumstances of pedestrian falls. We believe that a better understanding of risk factors will contribute to the implementation of safety strategies that create a safer environment for pedestrians. Given this, we set out to investigate the multifactorial influence on pedestrian falls in different countries simultaneously. Currently, there exists a dearth of comprehensive information regarding the multifaceted factors that contribute to pedestrian falls. The available data across various countries is partial in nature, characterized by the utilization of disparate methodologies in prior studies. Consequently, there is a notable absence of up-to-date data pertaining to the prevalence and severity of pedestrian falls. Previous research has demonstrated the influence of diverse factors such as age, gender, weather conditions, seasonal variations, socio-economic status, and the purpose or location of walking on pedestrian crashes. However, it remains crucial to ascertain whether these factors exhibit commonality across different cultures and countries or if they are context-specific. The pedestrian community encompasses a diverse range of individuals, exhibiting variations in numerous aspects. One aspect that remains unexplored pertains to the correlation between human physical activity and the occurrence of pedestrian falls. Despite pedestrians being the most susceptible users of roadways, they themselves may engage in hazardous behaviors, including non-compliance with traffic regulations and lack of attentiveness while walking, among others. Hence, it is of utmost importance to investigate how these risky behaviors manifest in instances of pedestrian falls and subsequent injuries.

## 2. Aims, methods and research sample

### 2.1. Aims

Instances of pedestrian falls not only result in injuries but, in more severe scenarios, can lead to fatalities while walking (Rod et al., 2021b), particularly within the context of traffic involvement. Paradoxically, little insight is available regarding the causative factors underlying pedestrian falls due to their omission from traffic accident classifications, consequently excluding them from traffic safety records. Based on the current body of knowledge, it is plausible to assume that the paramount underlying determinant is the quality of pedestrian infrastructure, akin to how vehicular speed significantly affects road traffic safety. Within this paper, our primary objective is to investigate the interplay between walkers' risky behaviours, such as distraction, and the occurrence of pedestrian falls. Building upon the Research gap elucidated in the preceding chapter, this study aims to achieve the following objectives:

a. To provide a broad overview of the prevalence and repercussions of pedestrian falls.
b. To conduct international comparisons of pedestrian fall rates and discern associated risk factors.
c. To scrutinize the intricate connections between the prevalence of falls and pedestrians' risky behaviour (defined as a behaviour which consciously or non-consciously exposes a pedestrian to a risk of injury).

To answer these questions, we conducted an international questionnaire study, which collected data in 16 different countries

**Table 1**
Demographics separated by country.

| | | Gender | | | | Age [years] | |
|---|---|---|---|---|---|---|---|
| Country | *N* | M | F | Other | Missing | *Min*–max | *M* ± *SD* |
| Australia | 879 (13.8 %) | 310 | 555 | 14 | | 17–88 | 42.88 ± 19.78 |
| Brazil | 281 (4.4 %) | 98 | 182 | 1 | | 11–79 | 32.35 ± 14.59 |
| Chile | 359 (5.6 %) | 148 | 210 | 1 | | 14–76 | 34.52 ± 13.05 |
| China | 280 (4.4 %) | 189 | 91 | | | 17–78 | 28.77 ± 9.67 |
| Colombia | 1,161 (18.2 %) | 533 | 628 | | | 5–78 | 23.74 ± 9.42 |
| Czech Republic | 342 (5.4 %) | 95 | 242 | 2 | 3 | 18–75 | 33.70 ± 12.81 |
| Finland | 177 (2.8 %) | 66 | 110 | 1 | | 18–70 | 33.77 ± 12.34 |
| Japan | 299 (4.7 %) | 228 | 71 | | | 18–23 | 19.08 ± 1.03 |
| Malaysia | 316 (5.0 %) | 146 | 168 | 2 | | 17–49 | 21.84 ± 5.85 |
| Mexico | 374 (5.9 %) | 132 | 242 | | | 16–77 | 28.19 ± 11.27 |
| Peru | 331 (5.2 %) | 72 | 255 | 4 | | 18–53 | 23.64 ± 5.67 |
| Portugal | 580 (9.1 %) | 284 | 294 | 2 | | 5–83 | 39.72 ± 16.74 |
| Romania | 299 (4.7 %) | 75 | 224 | | | 20–64 | 28.99 ± 10.44 |
| Spain | 436 (6.8 %) | 93 | 343 | | | 13–70 | 22.76 ± 8.50 |
| Turkey | 259 (4.1 %) | 120 | 139 | | | 18–73 | 35.69 ± 12.96 |

* N = number of participants; M = male; F = female; Other = gender without specification; Missing = missing variables; Min-max = minimum and maximum age, M = mean; SD = standard deviation.

dealing with walking in general (questionnaire is included as Annex 1 of this paper). For the topic of pedestrians' falls we include 15 countries (in one country data for this part were not collected). This work is based on the self-report data will all the limitations which this approach is connected to (participants may not respond truthfully, either because they cannot remember or because they wish to present themselves in a socially acceptable manner). Authors decided for this approach as other relevant data are not available or very complicated to collect. As falls are quite rare events, it is almost impossible to use field observation methods, hospital data or insurance data are of very low quality and, in many cases, not available, and as noted before, traffic accident data does not include pedestrian falls.

### 2.2. Research sample

A total of 6,373 participants from 15 different countries were recruited to take part in this study. Table 1 presents the demographic information by country.

### 2.3. Data collection

Researchers from all 16 participating nations were initially involved in this study to make it possible; however, for the purposes of this paper, only 15 countries were considered. We used a convenience sampling and snowball sampling approach; we selected participating countries on the basis of their availability. We used our professional networks and contacts. Data collection and collaboration between partners were managed by Queensland University of Technology, Australia. The partners that were involved were research institutions focusing on traffic safety. Researchers from each nation were in charge of either back-translating the survey into their own language or, if the survey had already been translated, editing the translated survey to make it suitable for their nation's unique linguistic characteristics. Additionally, it was up to the researchers to find participants inside their respective nations. All researchers were allowed to share the poll through university classrooms, related social media platforms, or websites because they were all connected to universities in their home nations. Small rewards, such as course credit, were given to certain participants. The Queensland University of Technology Human Research Ethics Committee approved the project (approval number 1800001243). Researcher-selected recruiting dates fell between March and December 2019 for participants from all nations, with the recruitment period covering the whole year. The survey's participation was optional and anonymous. The participant information page informed each participant of this. After completing the survey, participants were sent to a different form if incentives were being given. Participants were also informed that after the survey was submitted, they could not revoke their agreement due to anonymity. The average time spent by respondents on the survey was 27 min.

### 2.4. Questionnaire

The cross-sectional survey included demographic data covering age, gender, highest educational attainment (*no formal schooling, primary, secondary, diploma, undergraduate degree, postgraduate degree*) and employment status (*full-time or part-time work, full or part-time student, unemployed or retired*). To understand the importance of walking as a means of transport, questions for participants included their main mode of transport *(private motor vehicle, walking, bicycle, bus, train, personal electric vehicle*), how far participants lived from their city or town centre, and how much time they spent walking on an average day. The questionnaire used is attached as Appendix 1.

In concrete, for the purpose of this paper and to examine the consequences of pedestrian falls, we analysed the following 2 questions:

*In the past 3 years, how many times have you fallen while walking on the street or footpath?*

*If you have fallen, how many of these falls caused an injury that limited your regular activities for at least a day or caused you to go to see a doctor? Leave empty if you have not fallen.*

As for the "falls", we did not use any definition, as we were interested in any falls which respondents had experienced as pedestrians. In the second question, which we used for data analysis, we asked about injuries or a need to see a doctor. This enables us to distinguish between any falls which did not result in injury and those which resulted in minor or more serious injuries.

To cover the risky behaviour of pedestrians we used short version of Pedestrians behaviour scale (PBS) introduced by Granié et al. (2013). This questionnaire includes 23 questions. The instruction to answer was as follows: "The next set of questions ask about your behaviour as a pedestrian. How often do you do the following? Please tick the relevant box. Never/ very rarely /rarely / occasionally/ often /very often". We decided to use this scale as to our knowledge this scale is wildly used in the context of pedestrians' risky behaviour (what gives us a possibility to compare our data with the existing literature) and is reasonably short (we need to keep in mind that this scale is part of much robust questionnaire). This scale gives us an insight into the prevalence of risky behaviour (and its types) of pedestrians in different countries under the study. In the results section we present how risky behaviour is connected to prevalence of falls in different countries, respectively clusters of countries.

Short version of the PBS includes following items:

1. *I cross diagonally to save time.*
2. *I cross outside the pedestrian crossing even if there is one less than 50 m away.*
3. *I cross the street even though the pedestrian light is red.*
4. *I cross even though the light is still green for vehicles.*

5. *I cross the street between parked cars.*
6. *I start to cross on a pedestrian crossing, and I finish crossing diagonally to save time.*
7. *I cross between vehicles stopped on the roadway in traffic jams.*
8. *I walk on the roadway to be next to my friends on the sidewalk or to overtake someone who is walking slower than I am.*
9. *I forget to look before crossing because I am thinking about something else.*
10. *I forget to look before crossing because I want to join someone on the sidewalk on the other side.*
11. *I cross without looking because I am talking with someone.*
12. *I realize that I have crossed several streets and intersections without paying attention to traffic.*
13. *I get angry with another user and insult him.*
14. *I get angry with another user (pedestrian, driver, cyclist, etc.) and I yell at him.*
15. *I get angry with another user (pedestrian, driver, cyclist, etc.) and I make a hand gesture.*
16. *I get angry with a driver and hit his vehicle.*
17. *I let a car go by, even if I have the right-of-way, if there is no other vehicle behind it.*
18. *When I am accompanied by other pedestrians, I walk in single file on narrow sidewalks so as not to bother the pedestrians I meet.*
19. *I stop to let the pedestrians I meet by.*
20. *I walk on the right-hand side of the sidewalk so as not to bother the pedestrians I meet.*
21. *I walk for the pleasure of it.*
22. *I take public transportation (buses, metro, tramway, etc.).*
23. *I walk because I have no other choice.*

For the further analyses presented in the results section we have conducted factor analysis ending up with 4 factors: 1. minor offences, 2. distracted walking, 3. expressing anger (acting out), 4. inconsiderateness. A more detailed explanation is provided in Table 5 in the section 3.3.

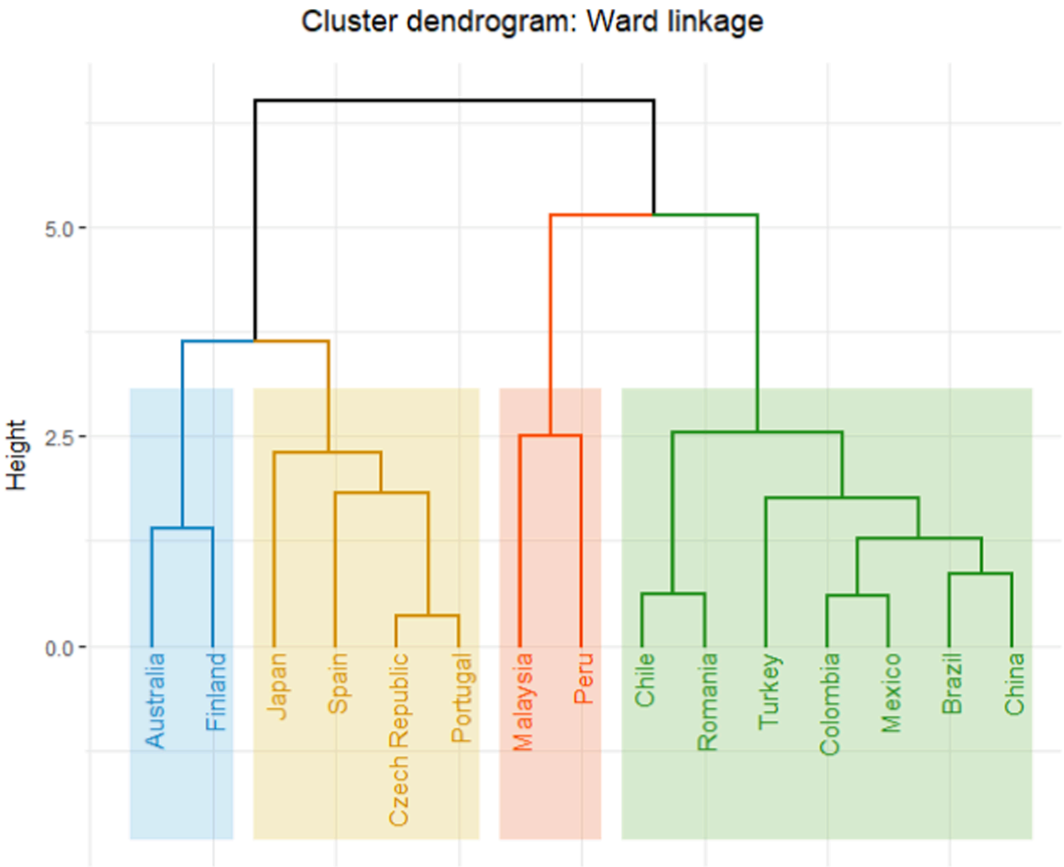


**Fig. 1.** Dendrogram. The data on the y-axis (Height) indicates the distance which the algorithm had to overcome in order to link the closest pair of clusters. The shorter the distance between the countries, the more similar the countries (e.g. Czech Republic + Portugal). The chart was created in R using the ggplot2 library (Wickham, 2016).

## 3. Results

### 3.1. Cluster analysis of countries

To identify groups of countries with a similar pedestrian transport situation, a hierarchical cluster analysis was performed. The countries were clustered according to four criteria:

1. **Road safety – number of road deaths per 100,000 inhabitants.** Road deaths were defined as those occurring within 30 days of the accident. These data were a mix of official national statistics (ITF, 2022; WHO, 2015, 2018) and statistical estimates adjusted for a 30-day definition of a road traffic death (used for only 3 countries: China, Mexico, and Peru; WHO, 2015, 2018). For all countries except Malaysia and China, the data refer to 2016 (for MYS and CHN, it is 2013).
2. **Road safety – share of pedestrians in road fatalities.** Same as above.
3. **Popularity of walking – modal share of walking.** Here the following served as sources: (a) national surveys (FIN, PRT, partly AUS, BRA, MEX); (b) sustainable urban mobility plans (all countries); (c) scientific articles on transport (CHL, CHN, JAP, MYS, ROM, TUR); (d) projects to promote active transport modes (PRT, ROM, ESP); (e) surveys and indices by other organisations (such as ICLEI, JICA, MobiliseYourCity, or Deloitte City Mobility Index). The data were systematically searched via Google; the keywords used were "modal split", "modal share", "walking", "pedestrians" and combinations thereof, always with the addition of the relevant country or prominent city in that country (e.g., "modal share Melbourne"). For each source found, we have noted which city/region of the country the data refers to and the year it comes from. From these data, we calculated a weighted average for each country, using the population of the city/region as a weight. On average, 7 credible sources were found for each country. 77 % of the data was from 2016 or later, the rest was from 2011 to 2015. We are aware of the fact (and concluding limitation) that this data is not recent. We used the most recent data available.
4. **Economic performance – nominal gross domestic product (GDP) per capita** in current USD. Data refer to 2016 (World Bank, 2022).

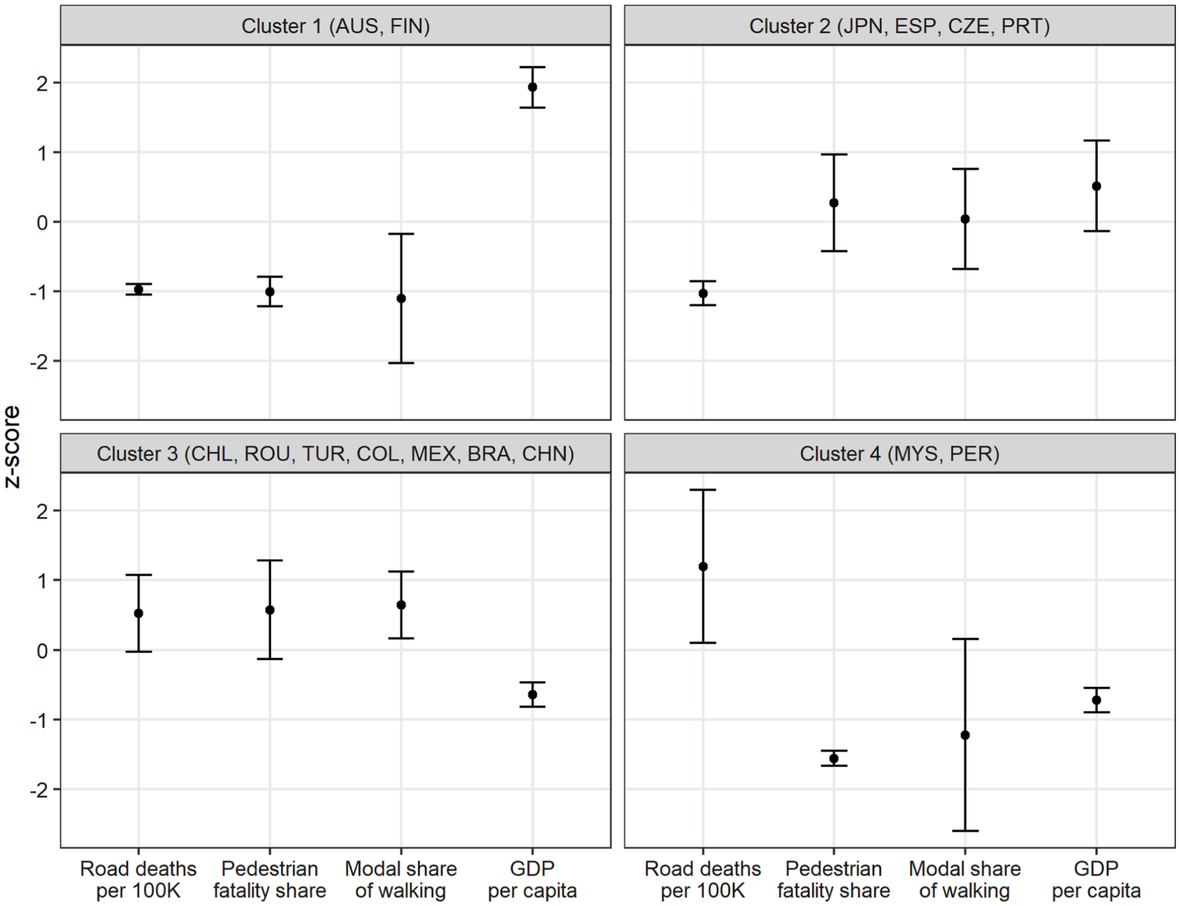


**Fig. 2.** Mean plot of z-scores in four criteria among clusters. Dots represent means, vertical lines represent standard deviations.

The analysis was conducted using the stats library functions in R (R Core Team, 2022). The hierarchical, specifically agglomerative, clustering approach was chosen. The Ward's minimum variance method was selected as a linkage function. The decision about the optimal number of clusters was made based on the visual assessment of both the dendrogram (Fig. 1) and the agglomeration schedule (i.e., length of steps). Cophenetic correlation (as an indicator of the quality of clustering) was $r(103) = 0.67$, $p < 0.001$, which is satisfactory.

The analysis produced four groups of countries (Fig. 1).

- Cluster 1 (two countries: Australia, Finland);
- Cluster 2 (four countries: Japan, Spain, Czech Republic, Portugal);
- Cluster 3 (seven countries: Chile, Romania, Turkey, Colombia, Mexico, Brazil, China);
- Cluster 4 (two countries: Malaysia, Peru).

The countries from Cluster 1 and 2 show low road mortality per 100,000 inhabitants. They are also relatively wealthy countries (especially Group 1). In addition, the Cluster 1 countries have a low share of pedestrians among road deaths, but this may also be because walking is less common there. Interestingly, in the Cluster 4 countries, the share of pedestrians in road deaths is low too, but this can be probably attributed to the fact that people do not walk there so much either. This is probably due to the known fact (e.g. Hakkert, Braimaister, & van Schagen, 2002) that exposure is a necessary condition for a hazard to become a risk.

The differences between the clusters according to four criteria (clustering variables) are shown in Fig. 2 and Table 2. Z-scores are given on the y-axis for comparison.

All subsequent analyses (statistical modelling) were performed on a cluster-by-cluster basis.

### *3.2. General description of the prevalence and consequences of pedestrians' falls – Based on clusters*

Only a subset of the full sample was used for descriptive statistics (and regression analysis). It was filtered according to the following criteria:

1. **Age** – at least 18.
2. **Gender** – either male or female. The respondents who identified themselves as "other" were excluded because there were only 27 such individuals (0.4 % of the total); from a statistical point of view, it would be unreliable, or even misleading, to make inference from such a small number of people (divided into four clusters moreover).
3. **The number of falls while walking in the past three years** was less than 30 and, at the same time, the number of falls resulting in injury did not exceed the total number of falls (other responses were considered dubious). The value of 30 was identified on the basis of the sampling distribution – the variable was highly skewed (the Fisher's moment coefficient of skewness = 48.9, min. = 0, max. = 1,000 falls) and the value of 30 corresponded to the 99.5 percentile (values above this threshold were seemingly outliers). The variable "number of falls while walking in the past three years" was obtained as a response to the question "*In the past 3 years, how many times have you fallen while walking on the street or footpath?*".
4. The fourth condition was added for the **number of falls while walking resulting in injury**: only those individuals who have experienced at least one fall while walking were included (still the number had to be less than 30, and the number of falls resulting in injury had to be smaller than the total number of falls). Other responses were considered dubious. The variable "number of falls while walking resulting in injury" was obtained as a response to the question "*If you have fallen, how many of these falls caused an injury that limited your regular activities for at least a day or caused you to go to see a doctor?*".

The first three conditions were met by 5,845 respondents, who reported an average of 1.39 falls while walking ($SD = 2.59$). ANOVA showed that the four clusters differed significantly in the average number of falls ($F(3; 5{,}841) = 14.11, p < 0.001$). The Tukey HSD test identified them in Cluster 4, which differs from all the remaining ones (all $p_{adj.} < 0.001$) – and exceeds all of them on average. The remaining pairs of clusters do not differ from each other. See Table 3 for the aggregated data on the number of falls reported by participants; means and standard deviations are provided in the header.

Zeros are highly predominant among the data – almost 55 % of the participants reported no falls while walking in the past three years and hence were excluded from further analysis (that of falls resulting in injury). The 2,648 respondents, constituting the remaining sample, experienced on average less than one fall resulting in injury ($M = 0.41$, $SD = 0.83$). Here, too, ANOVA identified

**Table 2**
Basic description of clusters in terms of four clustering variables.

| Variable | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 |
|---|---|---|---|---|
| 1. Road deaths per 100,000 inhabitants | Low rate of road fatalities | Low rate of road fatalities | Significant rate of road fatalities | High rate of road fatalities |
| 2. Share of pedestrians in road fatalities | and low rate of pedestrians killed in road accidents | but higher rate of pedestrians killed in road accidents | High rate of pedestrians killed in road accidents | Low rate of pedestrians killed in road accidents |
| 3. Modal share of walking | People do not walk much | People walk more (quite a lot) | People walk a lot | People do not walk much |
| 4. GDP per capita | Wealthy countries | Rather wealthy countries | Rather poor countries | Rather poor countries |

**Table 3**
M, SD, and numbers of falls while walking in the past three years in each cluster (regression analyses samples).

| Falls | Cluster 1 $M = 1.28$, $SD = 2.36$ N | % | Cluster 2 $M = 1.26$, $SD = 2.54$ N | % | Cluster 3 $M = 1.36$, $SD = 2.55$ N | % | Cluster 4 $M = 2.02$, $SD = 3.11$ N | % |
|---|---|---|---|---|---|---|---|---|
| 0 | 561 | 55.5 % | 996 | 62.1 % | 1,381 | 52.4 % | 259 | 43.5 % |
| 1–5 | 409 | 40.5 % | 527 | 32.8 % | 1,124 | 42.7 % | 288 | 48.3 % |
| 6–10 | 31 | 3.1 % | 57 | 3.6 % | 95 | 3.6 % | 39 | 6.5 % |
| 11–15 | 6 | 0.6 % | 20 | 1.2 % | 18 | 0.7 % | 4 | 0.7 % |
| 16–20 | 3 | 0.3 % | 4 | 0.2 % | 14 | 0.5 % | 6 | 1.0 % |
| 21–25 | 0 | 0.0 % | 1 | 0.1 % | 2 | 0.1 % | 0 | 0.0 % |
| Total | 1,010 | 100.0 % | 1,605 | 100.0 % | 2,634 | 100.0 % | 596 | 100.0 % |

Note: The number 25 was the highest recorded (among those who passed the filter for analysis).

significant differences between clusters concerning the average numbers of pedestrians' falls involving injury ($F(3; 2{,}644) = 8.39$, $p < 0.001$). The Tukey HSD test identified them again in Cluster 4, which differs from all the remaining ones ($p_{adj.} < 0.001$ from C3 and $p_{adj.} < 0.01$ from the remaining ones) – exceeds all of them on average again. The remaining pairs of clusters do not differ from each other. Descriptive statistics per cluster and breakdown of the number of falls with injuries are provided in Table 4.

The table shows that in clusters 1 to 3 almost 75 % of participants reported no injury; about 20 % experienced one fall resulting in injury. Cluster 4 seems to be different: only 60 % of falls ended without injury; 27 % of participants suffered one fall with injury. On average, there were 0.61 falls with injury, with Malaysia increasing the average (M = 0.87 falls). No other country (from the 15 selected) had recorded more falls with injuries than that.

### *3.3. Relationships between the prevalence of pedestrians' falls, personal characteristics, and their risky behavior*

#### *3.3.1. Factor analysis on Pedestrians' risky behavior scale (PBS)*

The *Pedestrian Risky Behavior Scale* (PBS) aims at various manifestations of risky behavior among pedestrians. However, not every type of risky behavior can be regarded as having a bearing on falls, or even injuries. We therefore did not settle for the aggregate score for all 23 items but conducted exploratory factor analysis first. The R software *EFAtools* (Steiner & Grieder, 2020) and *psych* (Revelle, 2021) libraries were used.

The number of factors was determined based on a scree plot of all 23 possible factors, parallel analysis, and sensibility of interpretation. The scree plot was assessed visually. There was a total of five factors with an eigenvalue > 1, but the fifth factor lagged significantly (eigenvalue = 1.16). The sharpest break in the graph seemed to occur after the fourth factor (the "scree" starting at the fifth factor). Parallel analysis was used to specify this. This recommended extracting five factors, but these did not appear to saturate the PBS items in a meaningful way. Therefore, four factors were eventually extracted which altogether explain 45.2 % of the response variance (see Table 5).

An orthogonal varimax rotation with Kaiser normalization was used to obtain a simple structure and calculate factor loadings. The minimal factor loading was 0.41 (item 17). Items 21, 22, and 23 do not come under any of the factors (their communality reached only 15 %, 9 %, and 5 %, respectively, which is not enough). They were therefore excluded from further analyses.

When calculating factor scores (or participants' results on individual factors), all items were weighted with 1, and a simple linear summation was made.

**Table 4**
M, SD, and numbers of falls while walking that caused a limiting or a medically treated injury in the past three years, in each cluster (regression analyses samples).

| Falls with injury | Cluster 1 $M = 0.39$, $SD = 0.84$ N | % | Cluster 2 $M = 0.40$, $SD = 0.86$ N | % | Cluster 3 $M = 0.35$, $SD = 0.75$ N | % | Cluster 4 $M = 0.61$, $SD = 1.01$ N | % |
|---|---|---|---|---|---|---|---|---|
| 0 | 325 | 72.4 % | 444 | 72.9 % | 934 | 74.5 % | 203 | 60.2 % |
| 1 | 94 | 20.9 % | 116 | 19.0 % | 241 | 19.2 % | 91 | 27.0 % |
| 2 | 23 | 5.1 % | 31 | 5.1 % | 52 | 4.2 % | 29 | 8.6 % |
| 3 | 2 | 0.4 % | 13 | 2.1 % | 13 | 1.0 % | 8 | 2.4 % |
| 4 | 1 | 0.2 % | 2 | 0.3 % | 5 | 0.4 % | 1 | 0.3 % |
| 5 | 1 | 0.2 % | 1 | 0.2 % | 7 | 0.6 % | 2 | 0.6 % |
| 6 | 2 | 0.4 % | 0 | 0.0 % | 0 | 0.0 % | 2 | 0.6 % |
| 7 | 0 | 0.0 % | 1 | 0.2 % | 0 | 0.0 % | 1 | 0.3 % |
| 8 | 1 | 0.2 % | 0 | 0.0 % | 1 | 0.1 % | 0 | 0.0 % |
| 9 | 0 | 0.0 % | 1 | 0.2 % | 0 | 0.0 % | 0 | 0.0 % |
| Total | 449 | 100.0 % | 609 | 100.0 % | 1,253 | 100.0 % | 337 | 100.0 % |

Note: The number 9 was the highest recorded (among those who passed the filter for analysis).

**Table 5**
Exploratory factor analysis results.

| Factor name | Factor description | Items | Statistics |
|---|---|---|---|
| Factor 1: minor offenses | events that happen on the streets daily, mostly without consequences (e.g., crossing the road outside a crosswalk) | 8 items (1–8) | average inter-item correlation = 0.43 Cronbach alpha = 0.86 eigenvalue = 3.61 explaining 15.7 % of the variance |
| Factor 2: distracted walking | risky behavior due to paying attention to something other than traffic (e.g., crossing the road without looking) | 4 items (9–12) | average inter-item correlation = 0.65 Cronbach alpha = 0.88 eigenvalue = 2.80 explaining 12.2 % of the variance |
| Factor 3: expressing anger (acting out) | behaviour when getting angry with another road user (e.g., shouting at them) | 4 items (13–16) | average inter-item correlation = 0.52 Cronbach alpha = 0.81 eigenvalue = 2.16 explaining 9.4 % of the variance |
| Factor 4: inconsiderateness | behavior that works against promoting a respectful traffic environment (e.g., not moving aside when meeting another pedestrian) | 4 items (17–20, all reversed) | average inter-item correlation = 0.38 Cronbach alpha = 0.71 eigenvalue = 1.81 explaining 7.9 % of the variance |

### 3.3.2. Regression models

A **negative binomial mixed-effects model** was chosen to model the number of falls or the number of injuries. The negative binomial (NB) model is a generalization of the Poisson model, the fundamental type of count data model. We always modeled the number of falls (number of injuries) first using Poisson regression, but these models always showed strong overdispersion (i.e. the conditional variance was significantly greater than the conditional mean). Unlike the Poisson model, the NB model does not have the limiting assumption of equidispersion (i.e. the conditional mean being equal to the conditional variance). It thus allows the problem of overdispersion to be dealt with. It does so by estimating the dispersion parameter, using the full maximum likelihood method. It is the maximum likelihood method that makes the NB model a better choice for us than, for example, the quasi-Poisson model, which uses a quasi-likelihood estimation (and it is not clear whether it is reasonable to use the qL estimation in the case of generalized linear mixed models; Bolker, 2010).

The results of negative binomial regression are presented in terms of *odds ratios* (OR), which are regression coefficients after exponential transformation. An odds ratio for a regressor indicates how many times an expected number of events (number of falls or injuries, as applicable) changes if the value of the regressor increases by unit and the other variables remain unchanged. An OR greater than 1 means the regressor increases the expected number of events. An OR smaller than 1 means the regressor decreases the expected number of events. The *intercept* shows the predicted mean number of events for a person with all the predictors in the model set to their reference values.

In our models, we used an offset term to counterbalance the exposure effect (the more a person walks, the more likely he or she is to fall; the more he or she falls, the more likely he or she is to suffer an injury). As a result, we no longer model *counts*, but *rates* (number of events per unit). *Intercept* thus indicates the odds of falling on one walking occasion or the odds of suffering an injury as a result of one fall.

All the models were fitted in the R software using the *glmmTMB* library (Brooks et al., 2017). Their quality was evaluated through the DHARMa library (Hartig, 2022), developed specifically for assessing the GLMM (generalized linear mixed models) category, which our models belong to because of the incorporation of a random factor.

### 3.3.3. Falls while walking

The first set of models addressed the **number of falls while walking in the past three years**. It was a numerical variable obtained as a response to the question "*In the past three years, how many times have you fallen while walking on the street or a footpath?*" Responses reporting more than 30 falls were considered dubious and such observations were therefore excluded from the analyses.

The regression equation for the falls model was as follows:

$$Y = e^{\beta_0} \bullet e^{\beta_1 X_1} \bullet \cdots \bullet e^{\beta_k X_k} \bullet e^{\gamma Z} \bullet E \bullet e^{\varepsilon}$$

where $Y$ is a dependent variable (number of falls), $\beta_0$ is a constant term, $X_i$ is a set of explanatory covariates (see below), $Z$ is a random intercept (country), $E$ is the exposure variable (frequency of walking), and $\varepsilon$ is the negative binomial error term; $e$ is a Euler number. $\beta_i$ and $\gamma$ are coefficients for the independent variables and a random term, respectively.

The following independent variables were chosen:

**Table 6**
Negative binomial regression results (response variable = number of falls while walking in the past three years).

| Variable | Cluster 1 ($N$ = 1,010) *OR* | 95 % CI for *OR* | Wald *Z* | *p* | Cluster 2 ($N$ = 1,605) *OR* | 95 % CI for *OR* | Wald *Z* | *p* | Cluster 3 ($N$ = 2,634) *OR* | 95 % CI for *OR* | Wald *Z* | *p* | Cluster 4 ($N$ = 596) *OR* | 95 % CI for *OR* | Wald *Z* | *p* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *(Intercept)* | 0.02 | [0.01, 0.04] | −11.39 | <0.001 | 0.02 | [0.01, 0.02] | –23.92 | <0.001 | 0.01 | [0.01, 0.02] | −19.03 | <0.001 | 0.03 | [0.01, 0.05] | −12.19 | <0.001 |
| Gender *(ref.: female)* | | | | | | | | | | | | | | | | |
| male | 0.66 | [0.52, 0.83] | −3.55 | <0.001 | 1.06 | [0.81, 1.38] | 0.40 | 0.690 | 0.78 | [0.68, 0.90] | −3.52 | <0.001 | 0.86 | [0.64, 1.15] | −1.03 | 0.305 |
| Age *(ref.: 18 years)* | | | | | | | | | | | | | | | | |
| linear term | 0.93 | [0.91, 0.96] | −4.99 | <0.001 | 0.91 | [0.88, 0.94] | −5.87 | <0.001 | 0.94 | [0.92, 0.96] | −6.07 | <0.001 | 0.92 | [0.86, 0.98] | −2.73 | 0.006 |
| quadratic term | 1.00 | [1.00, 1.00] | 3.28 | 0.001 | 1.00 | [1.00, 1.00] | 4.67 | <0.001 | 1.00 | [1.00, 1.00] | 4.50 | <0.001 | 1.00 | [1.00, 1.00] | 1.52 | 0.129 |
| Physical activity *(ref.: low)* | | | | | | | | | | | | | | | | |
| moderate | 0.89 | [0.63, 1.24] | −0.70 | 0.483 | 0.98 | [0.75, 1.29] | −0.13 | 0.897 | 1.22 | [1.01, 1.48] | 2.08 | 0.037 | 1.06 | [0.77, 1.46] | 0.35 | 0.724 |
| high | 1.08 | [0.77, 1.53] | 0.46 | 0.644 | 1.08 | [0.81, 1.44] | 0.51 | 0.609 | 1.36 | [1.13, 1.65] | 3.17 | 0.002 | 0.90 | [0.65, 1.24] | −0.64 | 0.524 |
| Walking *(ref.: 0)* | 0.82 | [0.77, 0.87] | −6.82 | <0.001 | 0.78 | [0.75, 0.82] | −9.48 | <0.001 | 0.78 | [0.75, 0.80] | −16.05 | <0.001 | 0.80 | [0.76, 0.84] | −8.73 | <0.001 |
| PBS factor 1–4 *(ref.: 0)* | | | | | | | | | | | | | | | | |
| F1: minor offences | 1.10 | [0.98, 1.24] | 1.59 | 0.113 | 1.27 | [1.12, 1.44] | 3.73 | <0.001 | 1.11 | [1.02, 1.20] | 2.57 | 0.010 | 1.29 | [1.11, 1.51] | 3.28 | 0.001 |
| F2: distracted walking | 1.08 | [0.97, 1.20] | 1.45 | 0.146 | 1.01 | [0.91, 1.13] | 0.22 | 0.826 | 1.21 | [1.12, 1.31] | 5.03 | <0.001 | 1.20 | [1.02, 1.42] | 2.21 | 0.027 |
| F3: expressing anger | 1.10 | [0.99, 1.23] | 1.74 | 0.082 | 1.11 | [1.00, 1.23] | 2.01 | 0.045 | 0.99 | [0.93, 1.07] | −0.18 | 0.856 | 0.96 | [0.82, 1.12] | −0.53 | 0.597 |
| F4: inconsiderateness | 0.96 | [0.86, 1.07] | −0.73 | 0.465 | 1.08 | [0.97, 1.21] | 1.36 | 0.173 | 1.02 | [0.95, 1.09] | 0.50 | 0.618 | 1.01 | [0.88, 1.16] | 0.13 | 0.899 |
| Country *(random effect)* | $SD = 0.35, p < 0.001$ | | | | $SD = 0.12, p = 0.284$ | | | | $SD = 0.51, p < 0.001$ | | | | $SD = 0.33, p < 0.001$ | | | |

Cluster 1: conditional $R^2 = 0.37$, marginal $R^2 = 0.29$.
Cluster 2: conditional $R^2 = 0.40$, marginal $R^2 = 0.39$.
Cluster 3: conditional $R^2 = 0.42$, marginal $R^2 = 0.26$.
Cluster 4: conditional $R^2 = 0.53$, marginal $R^2 = 0.44$.

- **Gender:** a categorical variable with "male" and "female" options. Females were set as the reference category.
- **Age:** Before being incorporated into the model, the variable was centered by Fig. 18 (i.e. the age of the youngest respondent under analysis) being deducted; the intercept therefore stands for 18-year-olds.
- **Physical activity:** a categorical variable with the "low", "moderate", and "high" options. It was created as follows: the originally continuous variable reflecting an aggregate level of physical exercise, excluding walking (constituting a separate category below), in the past seven days was ranked by size and divided into thirds. Low physical activity was set as the reference category.
- **Walking:** a numerical variable indicating the number of days in the past seven days on which the respondent engaged in walking for at least 10 min at a time.
- **PBS factor 1–4:** four continuous variables showing a participant's score on four PBS factors. They are standardized to a z-score before being incorporated into the model ($M = 0$, $SD = 1$).

We ran four regressions, one for each cluster. The results for each model are provided in Table 6.

The intercept stands for an 18-year-old woman who has had little physical exercise recently, does no walking at all, and shows an average score on all the PBS scales (i.e. z-score 0). If this person comes from the Cluster 1 country (AUS or FIN), the model presumes for her the odds 0.02 = 1: 46 (i.e. 2.1 % probability) of falling while walking. For Cluster 2 (JPN, ESP, CZE, PRT) these odds are 1: 62 (1.6 % probability), for Cluster 3 (CHL, ROU, TUR, COL, MEX, BRA, CHN) the odds are 1: 69 (1.4 % probability), and for Cluster 4 (MYS, PER) the odds are 1: 40 (2.5 % probability). These odds vary with the effect of different regressors (below) being taken into account.

**Gender**: Its effect varies across clusters. In clusters 1 and 3, females are more likely to fall than males (males' odds of falling are significantly smaller than those of females, $p < 0.001$).

**Age**: Generally speaking, people of younger age report greater numbers of falls in comparison to older respondents irrespective of the cluster ($p$ at least $< 0.01$ in all the cases). At the same time, the relationship between age and odds of falling is exponential rather than linear (except for Cluster 4, p is at least $< 0.01$ in all the cases), specifically convex (U-shape). Thus, young people's odds of falling are the greatest. The odds then decline: they maintain the lowest levels during middle age and do not go up again until the retirement age, still keeping at lower levels in comparison with those reported by young people.

**Walking**: It seems to hold for all the clusters that the more a person walks, the less he or she falls ($p < 0.001$). The way we can understand this is that when a person walks a lot he or she is "practised in walking and knows how not to fall".

**Physical activity** other than walking plays a major role in Cluster 3 only. It acts, perhaps surprisingly, as a risk factor (increasing the odds of falling): moderate physical activity presents a 1.22 times higher risk of fall than low physical activity ($p < 0.01$), while a high level of physical activity constitutes a 1.36 times higher risk than low activity ($p < 0.001$). The regressor as a whole is also significant ($\chi^2(2) = 10.03$, $p < 0.01$).

**Risky behavior while walking (PBS)** appears to increase the odds of falling in general. *Minor offenses while walking* (Factor 1) is the pedestrians' behavior that involves the greatest risk concerning falls – it significantly increases the odds of falling in Cluster 2 ($p < 0.001$), Cluster 3 ($p < 0.05$), and Cluster 4 ($p < 0.01$). *Distracted walking* (Factor 2) is also dangerous in this respect – it has a major impact in Cluster 3 ($p < 0.001$) and Cluster 4 ($p < 0.05$). (That is thus all for C3 and C4.) There is also a marginal effect of *expressing anger in road traffic* (Factor 3), which has a significant bearing in Cluster 2 ($p < 0.05$) and also comes close to significant in Cluster 1 ($p < 0.10$). (That is thus all for C1 and C2 too.) Factor 4 (*inconsiderateness in road traffic*) showed no relationship with the risk of pedestrians falling in any of the clusters.

Finally, we will comment on the random factor **Country**. Its significance was demonstrated in clusters 1, 3, and 4 (LR test of the full and reduced model: all $p$-values $< 0.001$) – varying the intercept by country will yield significant refinements in the predictions of these models. Although one may now question the significance of the clustering, we have decided to keep the countries divided into four groups as suggested by the cluster analysis. The rationale for this was that we wanted to stick to the theoretical reason for believing that the countries in a given cluster would be similar. The finding that this is not the case is also a finding.

To sum up, in all the clusters age and walking have consistent effects on pedestrian falls (being middle-aged and using walking as a mode of transport help in reducing the risk of falls). A completely different situation is observed for gender, the effect of which varies greatly across clusters in terms of both direction and strength. Pedestrians' risk behavior generally increases the odds of falling, with minor walking offenses appearing to pose the greatest risk (PBS Factor 1).

#### *3.3.4. Falls while walking resulting in injury*

The second set of models addressed the **number of injuries resulting from falls** while walking in the past three years. It was a numerical variable obtained as a response to the question "*If you have fallen, how many of these falls caused an injury that limited your regular activities for at least a day or caused you to go to see a doctor? Leave empty if you have not fallen.*" Only those respondents who had experienced at least one fall but not more than 30 were included in the analyses. Those who provided inconsistent responses, i.e. reporting more falls with injuries than falls in general, were excluded.

The regression equation for the injuries model was as follows:

$$Y = e^{\beta_0} \bullet e^{\beta_1 X_1} \bullet \cdots \bullet e^{\beta_k X_k} \bullet e^{\gamma Z} \bullet E \bullet e^{\varepsilon}$$

where $Y$ is a dependent variable (number of injuries), $\beta_0$ is a constant term, $X_i$ is a set of explanatory covariates (the same as in the previous case, apart from Walk – not included now), $Z$ is a random intercept (country), $E$ is the exposure variable (number of falls), and $\varepsilon$ is the negative binomial error term; $e$ is a Euler number. $\beta_i$ and $\gamma$ are coefficients for the independent variables and a random term, respectively.

**Table 7**
Negative binomial regression results (response variable = number of falls while walking in the past three years that caused an injury).

| Variable | Cluster 1 ($N$ = 449) *OR* | 95 % CI for *OR* | Wald *Z* | *p* | Cluster 2 ($N$ = 609) *OR* | 95 % CI for *OR* | Wald *Z* | *p* | Cluster 3 ($N$ = 1,253) *OR* | 95 % CI for *OR* | Wald *Z* | *p* | Cluster 4 ($N$ = 337) *OR* | 95 % CI for *OR* | Wald *Z* | *p* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *(Intercept)* | 0.03 | [0.01, 0.08] | −7.03 | <0.001 | 0.07 | [0.05, 0.11] | −11.90 | <0.001 | 0.08 | [0.06, 0.13] | −11.71 | <0.001 | 0.18 | [0.11, 0.30] | −6.57 | <0.001 |
| Gender *(ref.: female)* | | | | | | | | | | | | | | | | |
| male | 0.86 | [0.58, 1.25] | −0.80 | 0.421 | 0.95 | [0.69, 1.31] | −0.31 | 0.759 | 0.81 | [0.64, 1.02] | −1.77 | 0.077 | 1.37 | [0.92, 2.02] | 1.56 | 0.118 |
| Age *(ref.: 18 years)* | | | | | | | | | | | | | | | | |
| linear term | 1.07 | [1.03, 1.11] | 3.91 | <0.001 | 1.04 | [1.01, 1.07] | 2.50 | 0.013 | 1.00 | [0.96, 1.04] | −0.06 | 0.950 | 0.97 | [0.89, 1.06] | −0.57 | 0.567 |
| quadratic term | 1.00 | [1.00, 1.00] | −2.83 | 0.005 | 1.00 | [1.00, 1.00] | −0.92 | 0.357 | 1.00 | [1.00, 1.00] | 0.86 | 0.391 | 1.00 | [1.00, 1.00] | 0.42 | 0.674 |
| Physical activity *(ref.: low)* | | | | | | | | | | | | | | | | |
| moderate | 1.78 | [0.93, 3.41] | 1.75 | 0.080 | 1.20 | [0.77, 1.89] | 0.80 | 0.422 | 1.59 | [1.11, 2.27] | 2.54 | 0.011 | 1.03 | [0.66, 1.61] | 0.14 | 0.888 |
| high | 2.07 | [1.09, 3.91] | 2.24 | 0.025 | 1.52 | [0.98, 2.36] | 1.89 | 0.059 | 1.79 | [1.26, 2.53] | 3.26 | 0.001 | 0.89 | [0.59, 1.36] | −0.52 | 0.603 |
| PBS factor 1–4 *(ref.: 0)* | | | | | | | | | | | | | | | | |
| F1: minor offences | 0.80 | [0.67, 0.96] | −2.45 | 0.014 | 1.03 | [0.86, 1.24] | 0.33 | 0.739 | 0.96 | [0.85, 1.08] | −0.65 | 0.518 | 0.78 | [0.64, 0.96] | −2.41 | 0.016 |
| F2: distracted walking | 0.96 | [0.79, 1.16] | −0.42 | 0.676 | 0.95 | [0.81, 1.13] | −0.54 | 0.590 | 0.99 | [0.88, 1.11] | −0.16 | 0.873 | 1.13 | [0.91, 1.41] | 1.12 | 0.261 |
| F3: expressing anger | 1.11 | [0.95, 1.29] | 1.28 | 0.202 | 1.08 | [0.92, 1.26] | 0.92 | 0.356 | 1.17 | [1.05, 1.30] | 2.95 | 0.003 | 1.23 | [1.01, 1.50] | 2.11 | 0.035 |
| F4: inconsiderateness | 0.86 | [0.71, 1.03] | −1.66 | 0.096 | 1.08 | [0.93, 1.25] | 1.03 | 0.303 | 0.99 | [0.89, 1.10] | −0.22 | 0.828 | 1.03 | [0.86, 1.23] | 0.33 | 0.744 |
| Country *(random effect)* | $SD$ = 0.49, $p$ < 0.001 | | | | $SD$ = 0.00, $p$ = 1.000 | | | | $SD$ = 0.28, $p$ = 0.009 | | | | $SD$ = 0.24, $p$ = 0.091 | | | |

Cluster 1: conditional $R^2 = 0.08$, marginal $R^2 = 0.05$.
Cluster 2: conditional $R^2 = 0.02$, marginal $R^2 = 0.02$.
Cluster 3: conditional $R^2 = 0.02$, marginal $R^2 = 0.01$.
Cluster 4: conditional $R^2 = 0.05$, marginal $R^2 = 0.03$.

Again, we ran four regressions, one for each cluster. The results for each model are shown in Table 7.

The *intercept* stands for an 18-year-old woman who has had low physical activity recently and shows average scores on all the PBS scales (i.e. z-score 0). If she is from the Cluster 1 country (AUS or FIN), her odds of suffering injury as a result of a fall while walking according to the model are $0.03 = 1{:}\ 30$ (i.e. 3.2 % probability). For Cluster 2 (JPN, ESP, CZE, PRT) these odds are 1: 14 (6.8 % probability); for Cluster 3 (CHL, ROU, TUR, COL, MEX, BRA, CHN) the odds are 1: 12 (7.7 % probability), and for Cluster 4 (MYS, PER) 1: 5.5 (15.0 % probability). These odds vary when the effects of different regressors are considered.

**Gender**: has no significant effects.

**Age**: The effect of age can only be found in Clusters C1 and C2. It is exactly the opposite of what we described in the model for falls: older people tend to report generally more injuries than their younger counterparts ($p$ at least $< 0.05$ in both cases). At the same time, however, in Cluster 1, the relationship between age and odds of injury is quadratic rather than linear ($p < 0.01$), specifically concave (inverted U-shape). Young people are thus least likely to suffer injuries because of falls. The odds grow with time: in Cluster 1 they are (surprisingly) the greatest in the middle age and then they decline again during the retirement age. They do not go down enough to reach levels that are lower than those for young people.

**Physical activity** other than walking influences the risk of injury as a result of fall while walking – higher levels of physical activity in clusters C1 and C3 (with some benevolence in C2 too) are associated with a greater probability of harm as a result of a fall while walking. Its overall effect shows the greatest significance in Cluster C3 ($\chi^2(2) = 10.61$, $p < 0.01$), with the other clusters lagging (Cluster 1: $\chi^2(2) = 5.12$, $p < 0.10$; Cluster 2: $\chi^2(2) = 4.14$, $p = 0.13$).

The effect of **risky behavior while walking (PBS) (PBS)** on the probability of injury from a fall while walking is not so evident and consistent here as in the model for falls. In clusters C1 and C4, *minor offenses while walking* (Factor 1) reduce the odds of falls leading to injury ($p < 0.05$ in both cases). A paradoxical phenomenon can thus be observed where minor offenses while walking increases the risk of falls, nevertheless, such falls are not serious (they may involve a mere stumble). Additionally, *expressing anger in road traffic* (Factor 3) in clusters C3 and C4 increases the odds of a person sustaining an injury from a fall while walking ($p$ at least $< 0.05$ in both cases). Surprisingly, *distracted walking* (Factor 2) is not associated with the risk of injury resulting from a fall in any cluster and neither is *inconsiderateness in road traffic* (Factor 4).

Finally, we will comment on the random factor **Country**. Its significance was demonstrated in clusters 1 and 3 (LR test of the full and reduced model: both $p$–values at least $< 0.001$) – varying the intercept by country will yield significant refinements in the predictions of these models. The rationale behind keeping the division of countries into four clusters was the same as for the falls models.

To sum up, this time no regressor has a consistent effect on pedestrians' injuries from falls in all the clusters. Age (in Cluster 1) has the opposite effect than that in the model for falls and its influence on injuries has an inverted U-shape. Gender has a diverse effect across clusters in terms of both direction and strength. Physical activity generally increases the odds of injury from falls and so does expressing anger in road traffic (BPS Factor 3). On the other hand, minor offenses while walking (BPS Factor 1) decrease such odds.

## 4. Discussion

The aim of this study is to describe at a general level the prevalence and consequences of pedestrian falls and injuries in different countries. It is an attempt to identify risk factors in the framework of an international comparison of pedestrian falls. Not least, the relationship between the prevalence of falls and pedestrian risk behavior should be examined.

The findings of this study show considerable disparities among countries concerning the frequency of walking, as well as the varying levels of accidents and their severity in relation to exposure. When it comes to evaluating the modal share of walking—a measure of the proportion of people who primarily walk in their daily commutes—there is a nuanced challenge. The perceptions of what constitutes "walking much" or "not walking much" likely hinge on comparisons to local or regional norms. For instance, what might be considered minimal walking for an individual in Peru might be deemed substantial walking in a European country. Thus, while the modal share of walking could potentially serve as an indicator of walking habits and experience, it is important not to overinterpret the relationships between this variable and the other factors across different countries. Given the data at hand, it is prudent to concentrate on specific factors in one's interpretation, such as age and gender, as well as on the behavioral aspects gauged through the questionnaire.

As far as falls in general are concerned, results concerning gender are not homogeneous across clus-ters. But at least in two cluster areas (1 and 3), women's falls are significantly more frequent, while there are no significant differences in clusters 2 and 4. If one takes the liberty to assume that women generally walk more than males (there is some support for this assumption at least as far as leisure wal-king is concerned; see Pollard & Wagnild, 2017), one could find one reason for potentially higher involve-ment of women in falls, there. However, it is also possible that women do not fall more often – despite higher exposure and possibly as a consequence of more walking experience – but that they report falls without any injuries more consistently than men. The reason why they do not report more falls with injuries might be that the reporting of falls causing injuries would be more reliable in both groups.

By delving into age and gender, we can uncover how these demographics influence walking behaviors and potential accident rates. The questionnaire, being a direct tool to gauge behaviour, provides valuable insights into the tendencies, attitudes, and practices related to walking. This approach allows for a more concrete and comparative exploration of walking habits and their consequences. Concerning age, young people's odds of falling are the greatest. These odds decline towards middle age, where they reach the lowest level. They go up again at retirement age but remain at lower levels in comparison with those reported by young people. With the data at disposal, it is difficult to interpret these results. One explanation could be that young persons are less cautious because of their low level of, both, vulnerability, and perceived vulnerability (Wargo, 2007). Indeed, previous research has demonstrated that older adults have a higher risk (Rod et al., 2021b) and perceptions of risk (Rod et al., 2023) regarding falls and their consequences. Probably, they have good reason to look at things like this; when considering injuries in connection with falls, people of older age are much more at risk than younger age groups. The risk of being injured grows with age. This does suggest that vulnerability, or fragility, may lie behind these results (Kim & Ulfarsson, 2019).

Interestingly, results in this study indicate that the more a person walks, the less he or she falls. This needs to be interpreted with a Caveat because of the weakness of the exposure criterion, as indi-cated above. However, accepting the result at first glance, the way we could understand this result is that walking "a lot" provides experience with walking practice, which might include skillful avoidance of falling. At the same time, it seems that "physical activity", in the understanding of the respondents in this study, does not overlap much with "walking". To make use of a cliché: We can see, in our mind, persons going to the gym by car. As well, mountain bikers, or mountain clim-bers, together with many other groups fit the image of persons who are in very good shape but are not experienced walkers in the everyday walking environment. The fact that, according to the present study, in three of the clusters higher levels of physical activity are associated with a greater probability of being injured in the frame of falls may be interpreted in a simple way, according to Ockham's razor: They fall more often and thus are injured more often.

Minor offenses during walking, as well as engaging in distracted walking and expressing frustration towards fellow road users, markedly elevate the likelihood of experiencing a fall. This sort of "careless" conduct and the inclination to divert one's attention away from the immediate path could amplify the risk of stumbling or slipping. Interestingly, minor offenses appear to coincide with fewer severe injuries when falling as a pedestrian. This suggests that falls stemming from minor infractions tend to be less severe, potentially implying that walkers exercise increased vigilance when committing minor rule violations. Contrarily, impolite conduct among walkers does not exhibit any noteworthy correlation with the frequency of falls. It's possible that what's considered "impolite behavior" within the context of the Pedestrian Behaviour System (PBS) might not be as inconsiderate as initially assumed. Moreover, both inconsiderate behavior and distracted behaviour, as categorized by PBS, aren't linked to an elevated risk of injury as a result of a fall. The solitary form of behavior in the PBS framework that exhibits an association with an escalated risk is the expression of anger during interactions with others. This suggests that such behavior substantially diverts attention, causing walkers to inadequately focus on the act of walking when consumed by anger and subsequently making them more susceptible to more serious falls.

## 5. Conclusions

In general, young individuals tend to experience more falls while walking compared to older age groups. However, as people age, the likelihood of sustaining injuries from falls increases. Women tend to report more frequent instances of falls compared to males, yet their risk of injury from falls is not greater than that of men. Engaging in regular walking is linked to a reduced risk of falling during walks. On the contrary, physical activity raises this risk and even amplifies the likelihood of injury from falls while walking. Similarly, expressing sudden anger during road traffic situations heightens the risk of falling, as does committing minor offenses while walking. However, engaging in minor offenses while walking doesn't seem to elevate the risk of injury associated with falls; rather, it appears to somewhat mitigate such risks.

According to literature (e.g., Pljakić et al., Schepers et al., 2017, Rod et al., 2023) pedestrian falls are connected, among other things, with shortcomings in the infrastructure, i.e. in road design both, on the macro and micro level. We suggest that there is a need to improve infrastructure in locations where there is increased pedestrian movement, particularly among older pedestrians who are at increased risk of injury and fatalities (Naumann et al., 2011). It is well known what could, or should, be done to make walking easier and safer. Lower and better-placed kerbs, more room to move for pedestrians, such as broader pavements, separation from cyclists, narrowed road crossings, and, in parallel, more time provided for crossing (i.e. longer green phases for walkers), etc., are important and well-known infrastructure-related measures that are not regularly, or even have hardly been, implemented in spite of the literature has pointed out these issues for many years (e.g. Naumann et al., 2011; Methorst, 2021). Another important measure that has been discussed for quite a long time is to reduce car speeds in inhabited areas, e.g. by implementing 30 km/h speed limits. Pucher and Dijkstra (2000), among others, discuss this issue in connection with the aspect of safety. Thereby they refer only implicitly to comfort and thus the ease of walking and the related lower risk of stumbling because of being distracted, while Risser et al. (2010) demonstrate more clearly that to reduce car speeds would be highly advantageous for walkers, especially for older ones.

Age and gender are usually also considered important contributors. Pedestrians' behavior should play a minor role. The present study hints in this direction. When acknowledging that regular walking is one of the most healthy and societally useful activities (Risser & Sucha, 2020a), society should thus focus on measures to improve the preconditions for walking in such a way that things improve from the perspective of walkers (Van Cauwenberg et al., 2014; Risser & Sucha, 2020b). This would help increase the portion of walkers by making walking safer and at the same time more comfortable, as the fear of falling is definitely to be seen as a factor involved in discomfort. Especially older people would benefit, as people need to rely on walking more as they get older (Risser et al., 2010).

This study has provided an initial glimpse into the factors contributing to pedestrian falls, expanding the limited existing literature. A more detailed exploration of preventive measures might be necessary. However, a variety of measures to mitigate the problems discussed here has been known for a long time. The problem is that such measures are not implemented. To address this, a comprehensive research effort is required. Among other things, the longstanding neglect of the pedestrian fall issue over decades reflects this problem of policy negligence concerning pedestrian safety and comfort. An inadequate understanding of these problems contributes to an unsafe traffic environment for walkers. Future research should focus on uncovering both immediate causes and broader contextual factors, leading to implementation of evidence-based interventions that prioritise pedestrian safety.

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## CRediT authorship contribution statement

**Matus Sucha:** Writing – review & editing, Writing – original draft, Validation, Funding acquisition, Formal analysis, Conceptualization. **Eva Sragova:** Formal analysis, Data curation. **Beata Suriakova:** Methodology, Investigation, Conceptualization. **Ralf Risser:** Writing – review & editing, Writing – original draft. **Romana Mazalova:** Writing – original draft. **Oscar Oviedo-Trespalacios:** Investigation. **Ania Włodarczyk:** Investigation. **Sibele D. Aquino:** Investigation. **Rusdi Rusli:** Investigation. **Sergio A. Useche:** Investigation. **Laura Martínez-Buelvas:** Investigation. **Maria de Fátima Pereira da Silva:** Investigation. **Ali Kemal Çelik:** Investigation. **Joonha Park:** Investigation. **Jorge Tiago Bastos:** Investigation. **Violeta Enea:** Investigation. **Gabriel Dorantes Argandar:** Investigation. **Samira Ramezani:** Investigation. **Miguel Barboza-Palomino:** Investigation. **Quan Yuan:** Investigation. **Tiina Rinne:** Investigation. **Jean Carlos Natividade:** Investigation. **Yonggang Wang:** Investigation.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.


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## Appendix A. Supplementary data

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