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Original Research

Systematic causality mapping of factors leading to accidental falls of older adults

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ABSTRACT

Introduction: According to WHO's statistical evidence, accidental falls are the second leading causes of death worldwide. This systematic literature review and meta-analysis aims to provide a holistic view of risk factors and unfold the missing or less addressed but crucial factors that lead to accidental falls of the older adults. It also intends to profile the risk factors at different levels, which helps exhibit the level of consistency relationship between various risk factors and falls.

Study design: Systematic literature review.

Methods: A systematic review on the risk factors leading to accidental falls of older adults by retrieving English journal papers published starting from 1980 was conducted on April 2018. A method of literature synthesis and causal mapping was adopted to aggregate those fall-leading factors into macro variables and a coherent causal tracing network was thereby built, which can reflect not only the causal relationship of various macro variables but also the "consistency of agreement" between macro variables and falls of the older adults.

Results: A hypothesized causal relationship diagram of 19 aggregated macro variables and their 31 causal relationship suggested by the observational evidences is demonstrated. The consistency relationship between macro variables and elderly accidental fall are summarized and demonstrated. Our analysis reveals that "Time", "Season" and "Weather" are three less-studied factors in the literature. In our comprehensive analysis, our study also indicates neglected countries and senior populations such as Africa and Oceania, which requires more attention from the research community and global funding agencies. It is found that major quantitative tools focus on the traditional statistical analysis.

Conclusion: With the accelerated aging and increase of longevity worldwide, national and regional policies, and public health programs to provide adequate care services for the older people are crucially needed in both industrialized and developing countries. Evidences identified in the research are valuable inputs for policy design and decision makers of different stakeholders and prevention design of risk factors for falls in the older adults. The categorization of research methods in different literature also suggests that more quantitative approaches including simulation, optimization in operational research, and maybe machine learning are needed to enrich the research paradigm. We suggest researchers to consider using our presented causal map and the way of building it and explore the possibility of extending this framework to uncover more research topics in health-related research.

1. Introduction

Accidental falls are the second leading causes of death globally [1]. According to the definition from WHO, "accidental fall" is defined as "an event which results in a person coming to rest inadvertently on the ground or floor or other lower level" [1]. When this happens to older adults, it not only causes physical injuries but may often lead to serious mental issues (such as depression developed during long-term rehabilitation or disability). Even more, accidental falls of older adults often introduce high medical and financial burden to the care providers and

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the society [2]. In the US, one third of adults with age ≥ 65 years old fall annually, where 20%–30% result in injuries [3,4]. In 2016, accidental falls caused 35,859 deaths in the US where 83% were older adults aged 65 years old and over [1]. In metropolitan France, 9412 people died from falls in 2011, of which 90% were aged 65 years old and over [5]. In Poland, accidental falls directly led to fractures in 5% of older adults who were living on their own and 20% of inpatients [6]. Prevention of accidental falls is a challenging, costly, and undervalued issue [6]. According to 21 studies from the mainland China, Hong Kong, Macao, Singapore, and Taiwan, the annual fall rate in Asian countries and regions is between 14.7% and 34% with an overall median annual incidence of 18% [7]. A comprehensive analysis done on six countries (i.e., China, Ghana, India, Mexico, the Russian Federation, and South Africa) found that injuries related to falls accounted for 65.7% of all injuries for adults aged 50 years and over [8].

In the literature, the studied risk factors of falls vary significantly depending on each research project's objectives, study settings, and the availability of data and information. There are both intrinsic and extrinsic risk factors [9]. The intrinsic factors include but not limited to age, gender [10,11], chronic diseases, acute diseases (e.g., acute myocardial infarction) [12], and deficiency of vitamins (such as vitamin D deficiency) [13]. Studies showed that age [14–16] is a key risk factor because older adults tend to have issues like vertigo, poor posture stability [4,17,18], poor vision [4,15,17,19], frailty [20,21], and other ageing-associated diseases [22–26] that lead to falls. Some chronic diseases including but not limited to neurological, musculoskeletal, and cardiovascular diseases are also main factors leading to increased risk of falls among older adults [16,27]. Regarding extrinsic factors, some studies discussed the possible causal relationships between the increased fall risk and the use of single or a combination of drugs. The use of Fall-Risk-Increasing-Drugs (FRIDs) [28,29] such as antihypertensive, non-steroidal anti-inflammatory drugs, hypnotics, diabetes medication, and sedatives has positive association with increased risk of falls and related injuries[30–37]. Substance abuse such as alcohol is also a major contributing factor [38,39]. Another extrinsic factor often discussed in the literature is personal and environmental settings, such as rugs scattered at the floor of the house, absence of non-slip material (flooring or anti-slippery pad in bathroom) at home[14,27,39,40], inadequate illumination [39,41], and unsafe steps or walkway [42]. Recent study showed that foot problems and inappropriate shoes can increase the risk of falls of older adults [43]. All aforementioned examples represent a large variation of risk factors for accidental falls among the older adults living in different countries or regions [7,44,45]. Due to the differences in social or cultural backgrounds, the leading factors may vary across different population cohorts.

2. Aim

This study aims to provide insights on risk factors associated with elderly accidental falls by using a systematic review of relevant studies in the literature and adopted meta-analysis to summarize the findings.

3. Objectives

3.1. Three objectives of this paper are to

- provide a holistic view of risk factors studied, and attempt to discover the underrepresented or neglected but important casual factors that lead to falls in older adults by using a systematic causal mapping method [46].
- construct a relational structure containing all causal relationships by identifying key factors that affect the fall of older adults through meta-analysis, which in turn will help scholars in relevant fields to understand the gap between the practice and research efforts;
- provide meta data and raw data extracted from each reviewed article for interested scholar to focus on investigation of a specific sub-group, or use this method in other research fields.

4. Methods

For achieving the aforementioned objectives, a searching, screening, and analyzing strategy comprising four steps was developed as follows:

4.1. Step one: comprehensive and systematic literature retrieval

First, we identified multiple databases that usually archive the targeted articles required for this study, including PubMed, MedlinePlus, Ovid, etc., and literature retrieval was mainly conducted in PubMed. Next, we identified relevant keywords or combinations of keywords defined by subject matter experts (SME) for literature retrieval, including "fall(s) and elderly **OR** senior **OR** older adults **OR** older people", "accidental fall(s) and elderly **OR** senior **OR** older adults **OR** older people" (refer to Table 1). We also make sure that the paper retrieved should not be published too early to maintain the content relevance. The time constraint is from year 1980 to present. It is worth noting that the data extracted from reviewed articles may reflect evidences collected earlier than 1980. After the preliminary search, we collected 37,914 studies which were published in more than 100 journals and conferences.

4.2. Step two: setting and deploying screening and classification criteria

We carried out a first-round screening according to the exclusion criteria shown in Tables 1 and 1,127articles were left for going through the second-round screening by applying criteria listed in Supplement I. Thereafter, 101 qualified studies (in Supplement II) were retained for the final comprehensive review.

The first-round screening of this paper was independently completed

Table 1
Definition on inclusion and exclusion criteria and search terms.

Search Criteria		
Inclusion Criteria		Exclusion Criteria
1 Select articles published from 1980 to present; 2 The abstract about fall-related risks in the elder people; 3 The research focused on the risk factors of falls in the elder adult.		1. Non-journal articles; 2. Non-English articles; 3 Editorials, commentaries, letters to the editor, academic dissertation, conference proceedings and news; 4. Duplicate findings from different databases; 5. Literatures without evidence support.
Search Items		
Fall(s)	Older people	Injury/Injuries
Falling	Elder people	Fracture
Trip over	The elderly	Risk factor(s)
Accidental fall(s)	Senior	Chronic/acute disease
Accidental falling	Ageing	Drugs
Trip over		Substance abuse
Fall risk		Environment
Risk of falls		Behavior
Unintentional fall		Health
		Cause
		Consequence
		Cost
		Economic

Items in a single column have "**OR**" relationship, the items in different columns have "**AND**" relationship. For example, "fall" **OR** "falls" **OR** "accidental fall" **OR** "accidental falls" in the first column, and "fall" **AND** "older people" **AND** "injury" across the three columns.

by two people using the inclusion and exclusion criteria. Thereafter, they carried out second-round screening according to the screening criteria defined in *Supplement I*. The third person checked both screeners' results and reconciled some differences accordingly.

We reviewed all 101 papers in details and extracted data (e.g., different risk factors, causal relationship, and study method, etc.) according to the research type and quality, and divided them into different categories (refer to Supplement I). We then bucketed our selected articles into the following four types of research.

1) Review article (16 papers)
2) Qualitative research (34 papers)
3) Quantitative research (43 papers)
4) Qualitative research combined with quantitative research (eight papers)

4.3. Step three: data extraction

The data and key results of 101 articles were recorded in the defined coding system (refer to Tables 2 and 3). Table 2 is the "References table" which includes: authors, full reference, method, population size, data collection method, age range, and population geography. While Table 3 is the "Links table" that contains information about causality extracted from each article. We use "initial variable", "intermediate variable" and "outcome variable" to represent the causal relationship of related variables. In addition, statistical features used for hypothesis test in different studies were also recorded in the table, which are "test used for significance", "estimated effect", and "effect standard deviation". Throughout the coding process, we not only recorded all hypothesized causal links, but also included intermediate variables involved in the causal pathway rather than simple independent variables associated with the risk of falls. For example, with the ageing process, older adults might experience physical, psychological, and emotional changes in different stages such as vision impairment followed by gait imbalance, fall-related psychological concerns (FRPCs) [47], and consequently higher possibility of accidental falls. And the coding process in the database tends to capture such cascading causalities (See Supplements III-V).

4.4. Step four: data synthesis

We adopted meta-analysis to summarize the results in the "References table" and "Links table" so that it is easy for presentation and interpretation. In this analysis, the strength and weakness of each causal relationship were determined by the results of multiple studies in the reviewed articles. We aggregated similar variables (similar meaning but used different wording in the original article) into 19 macro variables (Supplement VI). According to the research objectives, one may decide to use more than one macro variable to capture different levels of aggregation between a series of closely related relevant concepts. For instance, regarding the impact of environment on accidental falls, instead of using one-variable to describe environment factor, we used two macro variables: one was environment factor (e.g. inappropriate illumination) and the other was surface and platform to capture detailed causal relationship. Interested researchers can choose other macro-variables to synthesize data that best represent their research objectives.

5. Results

5.1. Geographic distribution

After such a comprehensive review, we were able to gather risk factors related to elderly falls and injuries from 34 countries and regions (*Supplement VII*). Most of these studies only examined falls of older adults in a single country. Few research papers covered results by comparing factors among multiple countries. Roughly 50% of reviewed studies are from Europe and North America countries and the reason may reside in the source of research funding, data availability, and studies published in English as reference, etc. Only four out of 101 papers provided data from Oceania and Africa. Even though more than 4.4 billion world population lives in Asia and mang countries are challenged by accelerated ageing demographic structure [48,49], only 18% studies addressed such a critical topic covering only seven countries and regions (i.e., China, Taiwan, Japan, India, South Korea, Singapore, and Thailand).

When taking a closer look at all the factors evaluated in studies from different geo-locations, we have discovered variations of fall-related risk factors (refer to Table 4). The differences may stem from country-specific population structure, cultural differences, social norms, infrastructure, social support system, and the degree of independence in the older adult population. Due to a limited number of studies addressing senior populations in Africa and Oceania, less than a handful of macro factors have been investigated out of total 19 macro factors. The studies examining African older adults were primarily aligned with studies from Asia, Europe, North America, and South America on factors like "disease", "Health conditions and physical characteristics", "Social-economic

Table 2
A sample in the 'References table' in Supplement I.

Year	Reference authors	Full reference	Method	Population size	Data collection method	Age range	Population geography
2006	Ziere, G. et al. (2006)	Ziere, G. et al. (2006). "Polypharmacy and falls in the middle age and elderly population." Br J Clin Pharmacol 61 (2): 218–223.	research article (multivariate logistic regression analysis)	6928	an interviewer administered questionnaire (face-to-face interviews)	>55	Rotterdam, Southwest Holland

Table 3
A sample in the 'Links table' in Supplement II.

Reference number	Link number	Initial variable	Test used for significance	Estimated effect (Odds ratio = OR, or P value)	Confidential interval	Intermediate variable	Aggregation intermediate variable	Outcome variable	Link-direction of association
53	651	Weaken lower limbs		OR = 0.328	95% CI: 0.185–0.581	fall	fall risks	resulted in injury (71.4%)	positive
10	155	balance impairment	chi-square test	P = 0.001	NA	fall	fall risks	Serious injuries included fractures, head injuries requiring hospitalization, joint dislocations or severe sprains, and lacerations requiring suturing.	positive

Table 4
The number of link occurrences of macro-variables according to six continents.

Number	Macro-variables of factors Number of link occurrence	Europe	North America	Asia	Oceania	South America	Africa
1	Diseases	47	21	35	0	28	2
2	Medicines	39	8	24	0	11	0
3	Health conditions and physical characteristics	45	30	19	0	17	17
4	Daily behaviors and attitudes	26	20	29	0	8	0
5	Preventive and facilities	11	10	4	12	8	0
6	Environment factors	8	4	6	1	7	0
7	Age	12	7	5	0	1	0
8	History of falls	10	5	6	0	1	0
9	Cognitive factors	3	4	0	0	2	0
10	Psychological factors	3	1	7	0	0	0
11	Social-economic factors	3	9	8	0	1	1
12	Gender	9	4	5	0	1	1
13	Location	5	19	0	5	1	0
14	Surface and platform	4	4	0	1	5	0
15	Assistive devices	0	1	3	0	3	0
16	Time	2	2	2	0	0	0
17	Season	2	0	1	0	0	0
18	Family factors	0	1	1	0	0	0
19	Weather	0	0	0	0	1	0

factors", and "Gender". The studies describing older adults in Oceania focused more on "Preventives and facilities" and "Environment factors" (Supplement VIII). Since the reviewed data points from Oceania and Africa were sparse, the risk factors of falls have not been fully evaluated for the senior population living in those regions. This presents a fact that those areas demand more attention from research resources in the field.

5.2. Analysis methods in different studies

Since it was challenging to gather longitudinal data to investigate the factors contributing to older adults' falls in the field, more than half of reviewed studies could only access data from archives (including digital database, historical records from governments, and hospitals). In the selected papers, 54 studies had the opportunities to collect first-hand data. Seven studies reported results using both archive data and first-hand data sets, which might be motivated by the need to compensate for insufficient volume of data for a particular research objective or population. The reviewed papers used various sampling methods, variable definitions, and estimation approaches to examine the relationships between risk factors and accidental fall. Supplement IX shows that 726 out of 1107 causal relationship links were evaluated using qualitative methods likely because many factors were not easy to measure or gather in a quantitative way. In the case of using quantitative evaluation, reviewed studies employed various statistical tests including Chi-square test, ANCOVA, and so on (Supplement IX).

5.3. Analysis of the causes of falls of older adults

Fig. 1 offers the overview of the aggregated 19 macro-variables and 31 causal relationships (i.e., links). Each link represents an aggregation of multiple original variables from previous studies and two legends were employed to further illustrate the results. The thickness of each link represents the frequency of a causal relationship studied in the reviewed literature. It is worth noting that the frequency does not necessarily mean the importance of the relationship but rather demonstrates the popularity of studying such relationship.

We evaluated the consistency of 19 pairs of casual relationships between the macro variables listed in both Fig. 1 and Table 4. Solid lines, dashed dotted line, and dotted line were used to represent three types of relationships in Fig. 1. Solid lines were used when "Consistency of Agreement" is strong, meaning that all the published results indicate a positive hypothesized causal relationship existing between input macro variable and resulting macro variable. In the 101 reviewed papers, nine macro variables, including "Diseases", "Health and physical characteristics", "Preventives and facilities", "History of falls", "Cognitive factors", "Psychological factors", "Location", "Surface and platform", and "Family factors" were identified as having a strong positive contribution to the risk of falls. It is noted that half of the major contributing factors are intrinsic (e.g., cognitive factors), and the other half are extrinsic (e.g., location). If a majority of published results indicated that there existed a positive causal relationship between an input macro-variable and a resulting macro-variable, we call it major agreement and used dashed dotted line in Fig. 1. Seven macro variables, i.e. "Medicines", "Daily behaviors and attitudes", "Environment factors", "Age", "Social-economic factors", "Gender", and "Assistive devices" were presented as major risk factors leading to elderly falls and injuries. Of course, there exist some opposite conclusions that were against the consistency of agreement. For instance, regarding FRIDs, De Vries et al. [28] had found that cardiovascular drugs digitalis and digoxin may increase the risk of falling, while statins may reduce the risk. We defined a minor "Consistency of Agreement" as no strong relationship between a pair of macro variables and used dotted lines in Fig. 1. For example, there was no study confirming that morning was always the time of the day when elderly falls happened, nor was winter definitely the season that led to more fall incidents. It is found that "Time", "Season", and "Weather" are three less-studied macro-variables in the literature from the meta-analysis. There are two references discussing the relationship between different time periods and fall incidents in older adults. One article addressed the impact of weather on the incidents of elderly falls. Therefore, we define "Consistency of Agreement" as minor for those causal links.

6. Discussion

This study offers several major contributions. A systematic method of causal mapping is adopted to aggregate data from multiple literatures and different research types into a coherent causal network, which can reflect not only the causal relationship of various macro variables but also the "consistency of agreement" between macro variables and falls of the older adults. Regarding the causality research between the fall-leading factors and falls in the older adults, this analysis exhibits a holistic picture with factors interacting at the same and different levels, which include *intrinsic factors* (individual health, habit, psychological status, medication) and *extrinsic factors* (weather, community, family). [8,26]In traditional empirical research, research was conducted on certain piece of the puzzle without aggregating those pieces to a complete one. Therefore, the scattered pieces cannot give researchers a holistic view of the picture, which would allow them to decide which certain piece should be filled or which area needs a piece. More importantly, developing policies or designing interventions requires bird's-eye view on all relevant causes and the contour of portraying their interacting effects.

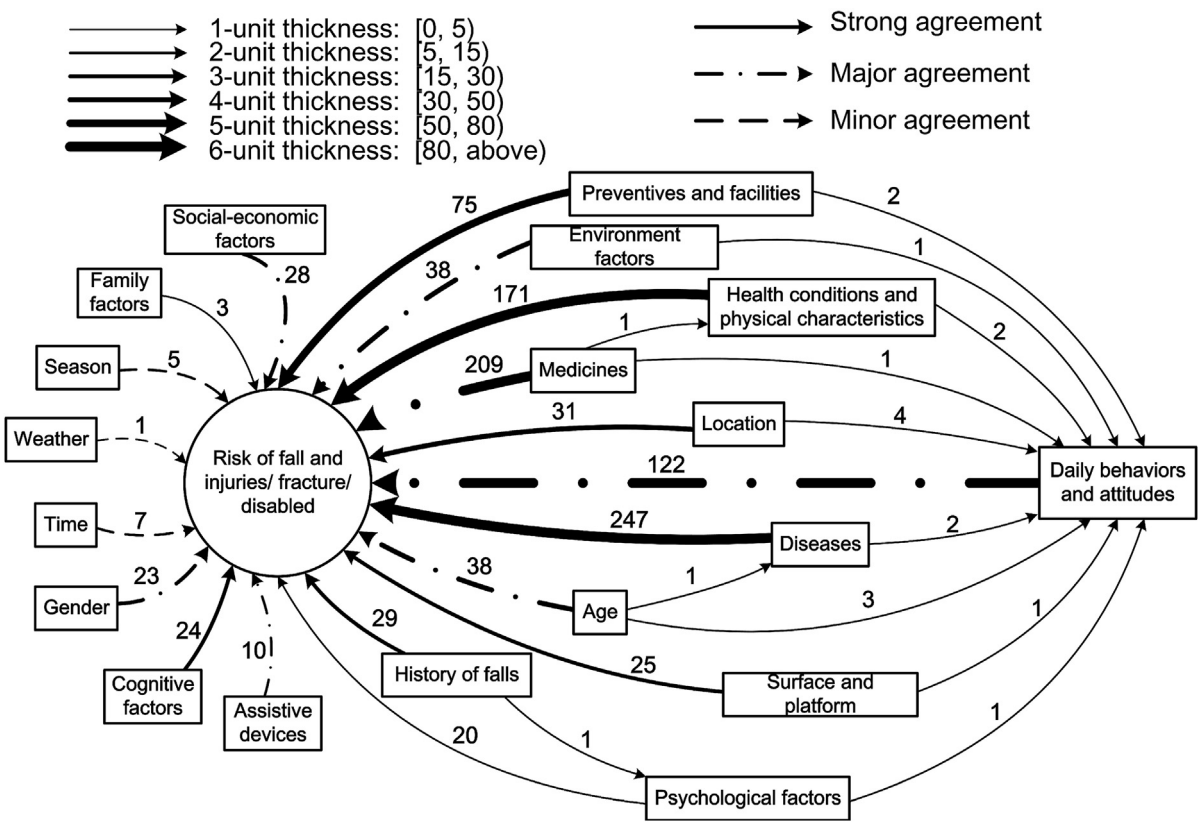

Fig. 1. Causal relationship of macro-variables.
Note:
1) The solid or dashed lines represent the strong or weak relationship between macro-variables and fall risk;
2) The numbers over the link (the weights of the lines) stand for the frequencies of those relations investigated in the selected and reviewed studies/papers.

The method in this study offers the latitude for future researchers to zoom in and zoom out (aggregating and disaggregating) with smooth transitions across different levels.

Secondly, our study reveals less-studied areas such as countries and regions in Africa and Oceania, which requires more attention from the research communities and global funding agencies.

Thirdly, the results of this research are able to provide researchers and practitioners with an overview on what studies have been conducted and how they are reflected in the causality tracing map and consequently identify gaps and opportunities in the relevant research. More importantly, it helps identify crucial but under-studied factors that may require to gather more data and evidence to fully understand such a complex group of causal relationships. Another example is the macro variable "Medicine" which highlights as a major factor leading to falls of older adults. Few quantitative evaluations have been conducted to examine the impacts of combination of multiple drugs on the increased risk of accidental fall. For instance, Seppala et al. [29] found that psychotropics drugs such as antipsychotics, antidepressants, and benzodiazepine drugs have been associated with the higher risk of fall. However, it is unclear whether specific subgroups such as short-acting benzodiazepines and selective serotonin reuptake inhibitors are safer in reducing the risk of falls. This can be a valuable topic for other researchers or even pharmaceutical companies to investigate and gather supporting evidence and data for various older populations in different regions where the medicine is to be distributed to address such concern.

Fourthly, the casual factors summarized from this review also provide some evidences to design high-leverage cost-effective prevention strategies by which decision makers can reasonably allocate resources to schemes dealing with different fall-causing factors, namely more resources to those factors contained in the major "Consistency of Agreement" and less sources to minor cases.

6.1. Strengths of causal-mapping synthesis analysis

By categorizing and causal-mapping those relevant variables, this research facilitates the big data collection for the sake of tracking mobility behavior and habits of older adults by which the comprehensive measures can be taken to mitigate those risk factors accordingly. With our systematic method and an ensuing simulation model, the results can help assess future interventions and their impacts. And the above method can be extended to investigate other health-related research.

Our framework has the flexibility to be an open-end database for easily integrating latest results of studies in the area of investigating causality between certain factors and the falls risk in the older adults. Such a dynamically interacting platform can not only improve the review efficiency for researchers but also accumulate knowledge for governments and agencies to gain better and holistic understanding on the impacts of different factors and their combinations thereof. This consequently helps design high-leverage interventions and initiate sustainable implementation.

6.2. Limitations

In this review, we provided one possible aggregation to create a general overview of the causes of falls of older adults. By aggregating multiple variables, macro variables may not be able to capture all detailed concepts of each original factors because their goal is to provide a concise view of relationship. Therefore, one should always refer to the details of each macro variable (in Supplement VI) to interpret the causal relationship.

Given the language constriction set upon literature search, it is possible that those retrieved journal papers may underrepresent the actual research in some non-English speaking countries and regions. This

may be enhanced by doing detailed national comparison analysis with several typically chosen countries or regions in the aforementioned six continents.

7. Conclusions

This comprehensive examination summarizes the risk factors for falls in the older adults. Studies on risk factors for elderly falls and injuries have been collected from 34 countries and regions. They reported mixed findings on the relationship between macro variables and elderly falls. Different from conventional literature reviews, causal mapping method is used in this study to profile the risk factors leading to accidental falls in the older adults at different level, which exhibits the level of consistency for relationship between various risk factors and falls.

This study has identified some key research gaps and made some related recommendations. Future research using more quantitative approaches including traditional statistical analysis, simulation (evaluating dynamic impacts alternatives), and optimization (optimal resource allocation) is needed. We suggest researchers to consider using our presented causal map and the way of building it and explore the possibility of extending this framework to uncover more research topics in health-related research.

With the accelerated aging and increase of longevity worldwide, national and regional policies and programs to provide adequate care services for the older adults are crucially needed in different countries. It is desirable to identify and develop successful models in well-performing countries and communities, and then disseminate them in other settings. Our study calls for more research and grant support regarding the design of more cost-effective prevention programs and infrastructures. Comparison analysis of ex ante (prevention interventions) and ex post (as is scenario) cost regarding prevention investment and treatment cost of fall-related injuries should be conducted in a forward-looking manner, which can raise the awareness of policy makers and promotes prevention-oriented interventions.

Declaration of competing interest

The authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhip.2020.100045.

Ethical approval and consent to participate

Not available.

Consent for publication

Not available.

Availability of supporting data

Relevant data and analysis results are provided in the attached three supplemental files.

(Microsoft excel files i.e., supplement I.xlsx, supplement II.xlsx, Supplement III.xlsx)

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Authors' contributions

All authors equally contributed to the production of this paper. Hongli Zhu (HLZ) searched and reviewed all the papers. HLZ drafted the papers. Kun Hu (KH) initiated the ideas, provided guidelines on the paper analysis and review the paper during the secondary paper selection. KH offered multiple version of major changes. Shiyong Liu (SYL), as Ph.D. advisor of HLZ, co-initiated the paper, reviewed the paper during the secondary paper selection and provided guidelines on the draft. SYL spent significant time to go through each revisions and changes and co-ordinated the circulation of the draft among different authors. Youfa Wang (YFW) offered invaluable inputs on formatting and structuring of this manuscript. YFW also provided indispensable helps in improving this manuscript. Ho-Cheol evaluated the method and provided domain expertise in studies of older population, and contributed in writing and revising the manuscript. Qianli Xue (QLX) provided holistic restructuring and formatting to this manuscript.

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