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Physical strength and mental health mediate the association between pain and falls (recurrent and/or injurious) among community-dwelling older adults in Singapore

Vanessa Koh [a,b,*], David B. Matchar [a,c], Angelique Chan [a,b]

[a] Programme in Health Services and Systems Research (HSSR), Duke-NUS Medical School, Singapore 169857, Singapore
[b] Centre for Ageing Research and Education (CARE), Duke-NUS Medical School, Singapore 169857, Singapore
[c] Department of Medicine (General Internal Medicine), Duke University Medical Center, 3116 N Duke St, Durham, NC 27704, USA

A R T I C L E I N F O

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Depression
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A B S T R A C T

Objective: This study aims to understand if poor physical strength and depression mediate the association between pain and recurrent and/or injurious falls in a community of older adults.

Methods: Data was obtained from a nationally representative longitudinal cohort study conducted in Singapore, PHASE (Wave I and II), which collected information from community-dwelling older adults above 60 years old. A hurdle negative binomial regression and binomial logistic regression were used to assess the association between pain and recurrent falls, and pain and injurious falls respectively. A subsequent mediation analysis was conducted.

Results: Almost half of the participants ($N = 1144$, 39.7%) reported having either mild, moderate, or severe pain at baseline, 166 (5.4%) participants experienced injurious falls and 144 (4.7%) participants experienced recurrent falls at Wave II. After adjusting for covariates, the presence of pain significantly influenced recurrent (OR 2.8; 95% CI: 1.8, 4.4) and injurious falls (OR: 1.8; 95% CI: 1.3, 2.5). Mediation analyses demonstrated that poor physical strength and depression had a significant mediation effect between all pain characteristics on recurrent falls. Poor physical strength partially mediates the effects of pain and injurious falls as well. However, the mediating effect of poor physical strength and depression was not observed between other pain characteristics and injurious falls.

Conclusions: The findings highlighted differences in the underlying mechanisms between pain characteristics affecting recurrent and injurious falls. These insights will be useful for identifying patients most at risk for recurrent or injurious falls, and for tailoring future community-based fall intervention programmes.

1. Introduction

Falls among older adults are a significant health concern and the second most common cause of accidental or unintentional injurious deaths globally (Stevens et al., 2008; Ang & How, 2020). Naturally, the likelihood of experiencing adverse events from falls is higher among those who suffer from recurrent and injurious falls. Falls, particularly recurrent falls, can result in fear of falling, subsequently inducing activity restriction, social isolation and loss of self-confidence (Jo et al., 2020). In addition, injurious falls contribute to unnecessary costs for healthcare institutions and governments worldwide. In 2015, the overall medical spending from fatal and nonfatal falls was approximately $50 billion in the United States (Florence et al., 2018). The impact on individuals' quality of life and the associated costs of falls highlights the pressing need to implement effective fall prevention strategies to reduce the incidence of falls, particularly for clinically important fall outcomes such as recurrent and injurious falls.

In older populations, multiple risk factors have been shown to be associated with falls. This includes poor physical strength, impaired balance and gait, systemic disease, and medication use (Gama & Gómez-Conesa, 2008; Xu et al., 2022). Falls are also associated with poor psychological health such as fear of falling and depression (Deandrea et al., 2010; Somadder et al., 2007). Notably, risk factors identified for recurrent and injurious falls may differ (Lloyd et al., 2009; Ku et al., 2013). Uncovering these differences will be beneficial in designing tailored fall intervention programmes.

* Corresponding author: Health Services and Systems Research, Duke-NUS Medical School, Singapore, 8 College Road, Singapore, Singapore 169857.
E-mail address: vanessa.kjw@u.duke.nus.edu (V. Koh).

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Pain is common among older adults and has been identified as a potential risk factor for falls (Arnold & Gyurcsik, 2012). Up to 50% of community-dwelling older adults experience pain Abdulla et al. (2013). Unfortunately, pain is often ignored by older adults as it is regarded as a natural part of aging (Noroozian et al., 2018; Wyman et al., 2018). Furthermore, detection and management of pain remain inadequate among community-dwelling older adults, and the majority of older adults with pain remain undertreated (Kaye et al., 2010). Pain is often linked to deteriorating physical strength (Gillespie et al., 2012; Mänty et al., 2014) and is significantly associated with depression (IsHak et al., 2018), both of which are frequently encountered in clinical settings. These factors have been increasingly discussed with regard to pain and falls separately, but have not been explored together, nor in the context of recurrent and injurious falls.

The mechanisms underlying the relationship between pain and recurrent and injurious falls remain poorly understood (Stubbs et al., 2014; Cai et al., 2021). As pain and falls are complex and multi-faceted, examining potential causal factors that directly and indirectly influence this relationship would contribute to the holistic identification and management of recurrent and injurious falls. To the best of the authors' knowledge, this is the first study in Asia examining the underlying mechanisms influencing the relationship between pain, recurrent and injurious falls respectively.

The present study aims to investigate whether: (a) pain characteristics, including the presence of pain and pain at specific painful sites, are independent risk factors for recurrent and injurious falls in an Asian context; (b) poor physical strength and mental health mediate the association between pain and recurrent and injurious falls in a community of older adults; and (c) whether there are differences in the relationship between pain and recurrent versus injurious falls.

2. Methods

2.1. Participants

Data was obtained from two waves (Baseline – Wave I: 2009; Wave II: 2011) of the Panel on Health and Aging of Singapore Elderly (PHASE), a nationally representative longitudinal survey of community-dwelling Singaporeans aged 60 years and older, carried out by the center for Ageing Research and Education. Details on methodology were described in a previous study elsewhere (Leung et al., 2016). 4990 participants were interviewed at Wave I, and 3103 participants responded in Wave II. As this analysis focuses on recurrent and injurious falls, we excluded single, non-injurious fallers ($n = 187$) from the analysis. Individuals reporting ethnicity as "other" were also excluded due to the small sample size ($n = 32$), resulting in a final cohort of 2884 community-dwelling older adults. The studies were approved by the institutional review board of the National University of Singapore. All participants signed an informed consent form before both surveys.

2.2. Hypothesis

We hypothesized that characteristics of pain would be associated with recurrent and injurious falls among community-dwelling older adults in Singapore. To clarify the causal relationship between pain and falls, we further hypothesized that poor physical strength and poor mental health, respectively, would mediate the relationship between pain and the different types of falls.

2.3. Independent variable

We defined the characteristics of pain as the presence of pain with at least lasting mild pain in the last 30 days, and the specific painful site contributing to pain. Participants were first asked if they had any bodily aches or pain (none, mild, moderate, severe, and extreme) at baseline. Participants who answered with mild to severe and extreme pain were then asked to indicate the specific painful site on the body (head, neck, shoulders, joints of the hands and arms, chest, abdomen, back, lower back, waist, and joints of the legs).

2.4. Dependent variable

Fall history and fall-related outcomes were collected only in Wave II of PHASE. Falls were defined as unintentionally coming to the ground or some lower level. Participants were evaluated with the question "Have you fallen in the last one year?". If "yes", participants were then asked to specify the number of falls they had in the past year. Recurrent fallers were defined as individuals who have fallen more than one time in the past year. The frequency of recurrent falls was used as the dependent variable in our regression analysis. Responses for recurrent fallers were also dichotomised (0 = no fall, 1 = recurrent fall) for further causal mediation analysis.

Injurious fallers were defined as individuals reporting falls with injuries for which they sought medical attention. Participants were evaluated with the question "In any of these falls, did you injure yourself seriously enough to need medical treatment (Yes/No)?". Participants who answered "Yes" were designated as injurious fallers. Responses for injurious fallers were dichotomised (0 = no fall, 1 = injurious fall) to assess pain characteristics on injurious falls by comparing them to individuals without falls.

2.5. Mediators

Physical strength was assessed using handgrip strength. Participants were asked to stand with arms in a neutral position. Measurements were taken twice for both dominant and non-dominant hands, with a short break between measurements. The performance of the handgrip strength assessment was expressed to the closest 0.5 kg, and the mean handgrip strength was calculated from the two measurements. Handgrip strength is a good measure of overall muscular strength (Trosclair et al., 2011) and is a good proxy for muscle mass among older Asian adults (Chan et al., 2022). Based on previous studies, the maximum value achieved from either hand was a summary measure of the isometric strength of the hand and forearm muscles (Steiber, 2016). For this study, handgrip strength assessment from the dominant hand was utilized for analyses.

Depression was assessed by the modified version of the 11-item Center for Epidemiologic studies-Depression (CES-D) scale (Kohout et al., 1993). Items on the scale were scored from 0 to 2 (none/rarely, sometimes, often) depending on how the participant was feeling over the past week. Total scores range from 0 to 22, where scores greater than 7 were classified as having clinically depressive symptoms. The CES-D scale used in this had been previously validated and showed good internal consistency reliability (Kohout et al., 1993).

2.6. Other covariates

The analyses were adjusted for baseline demographic and health-related variables collected in Wave I. Participants completed questionnaires that included age, sex, ethnic group, housing type and living arrangements. Housing type (1–2 room public housing, 3 or more room public housing, condominium/landed property) was used as a proxy for socioeconomic status. This method has been validated in the local context (Chan et al., 2011). Health-related variables included self-assessed vision status, poor physical strength, depression status, number of chronic diseases and polypharmacy.

Chronic diseases and polypharmacy were controlled in the analyses as they are established risk factors for falls. Participants were to declare any diagnosed chronic diseases from the following list: angina/myocardial infarction/any other heart condition, cancer, cerebrovascular diseases, high blood pressure, diabetes, respiratory illness, digestive illness, renal ailments, liver disease, arthritis, rheumatism, nerve pain, chronic back pain, osteoporosis, fractures, cataract, glaucoma, thyroid disease, and Parkinson's Disease. Participants who indicated "Yes" for any of the diseases above were asked if they were taking any physician-prescribed medication.

2.7. Statistical analysis

Descriptive statistics were performed to examine the group differences in demographic and health-related outcomes between fallers (participants with recurrent falls and/or injurious falls) and non-fallers. Students' t-tests and chi-square tests were performed for continuous and discrete variables respectively. The fisher exact test was performed for discrete variables with an expected cell count < 5. Descriptive statistics were also performed to examine the differences between recurrent and fallers, to understand any differences that distinguished the two types of fallers.

Separate regression analyses were conducted to investigate whether pain characteristics (presence of pain and specific painful sites) were independent risk factors for recurrent and injurious falls.

A hurdle negative binomial regression analysis was used to assess the association between pain and recurrent falls while controlling for potential risk factors discussed above. The two-part hurdle model was utilized due to excess zeros in the data from non-fallers. The first part is a binary logit model, focusing on the presence of recurrent falls or no falls at all. The second part is a truncated negative binomial regression that explains the frequency of recurrent falls conditional on some falls. Two models for pain characteristics were analyzed separately: (1) association between the presence of pain and recurrent falls and (2) association between specific painful sites and recurrent falls.

Binomial logistic regression analysis was used to assess pain and injurious falls while controlling for potential risk factors. Like the models for recurrent falls, two models were used to analyze pain characteristics: (1) association between the presence of pain and injurious falls and (2) association between specific painful sites and injurious falls.

Based on the findings from the above set of analyses, we then investigated whether physical strength and mental health, respectively, mediated the association between pain and fall outcomes. Single mediation models adjusted for demographic and health-related variables were performed, with a bootstrapping strategy to test the validity of indirect effects (Hayes, 2009). Each test was resampled 5000 times to estimate the bias-corrected and accelerated 95% confidence intervals.

All analyses were performed using R 4.0.3 (R Foundation for Statistical Computing, Vienna, Austria). The packages pscl (Jackman, 2020) and mediation (Tingley et al., 2014) were utilized for the hurdle model and causal mediation analyses respectively. We reported the first part (binary) of the two-part model as odds ratios with 95% confidence intervals, and the second part (truncated negative binomial) as coefficients with 95% intervals. Odds ratios with 95% confidence intervals were reported for binomial logistic regressions. Estimates and 95% confidence intervals were reported for causal mediation analyses. Two-tailed P-values < 0.05 were considered statistically significant in this study.

3. Results

3.1. Baseline participant characteristics

A total of 2884 participants completed the two-wave survey in 2009 and 2011. The mean age of the final cohort was 72.1 (7.8) years old, and 54.2% were women. The prevalence of pain was 39.7%, with 20.2% of participants having at least two painful sites. 144 (4.7%) participants had multiple falls and 166 participants (5.4%) experienced injurious falls. There were 49 (1.7%) participants who were both recurrent and injurious fallers. Among the recurrent fallers, 64.6% of participants suffered from pain and 39.6% of participants had at least two painful sites. 52.4% of injurious fallers were suffering from pain and 29.5% of them had at least two painful sites. Compared to non-fallers, recurrent fallers and injurious fallers were both likely to be older, have poorer self-assessed vision and hearing, be affected by pain, have depression, polypharmacy, have ADL and IADL limitations and weak handgrip strength (Table 1). Compared to injurious fallers, recurrent fallers were significantly more likely to have poorer hearing, experience pain and report more painful sites. The mean number of painful sites was 1.3 in recurrent fallers compared to 0.9 in injurious fallers (Table A.1).

3.2. Association between pain characteristics and recurrent falls

The presence of pain had a significant association with recurrent falls (OR 2.8; 95% CI: 1.8, 4.4; $P < 0.001$), and the frequency of falls increased among those with pain (0.4; 95% CI: 0.0, 0.8; $P < 0.05$) compared to those without pain. Malay and Indian ethnicities had significantly increased odds of falling, though the frequency of recurrent falls was lower compared to Chinese. A U-shape relationship was observed between self-assessed vision and recurrent falls.

The odds of recurrent falls were greatest among participants who rated "excellent" and "fair" vision, and the least among participants who rated "very good" and "good" (Table 2). The frequency of falls was significantly lower with participants with "good" vision (−0.4; 95% CI: −0.8, −0.1; $P < 0.05$). In addition, joint leg pain (OR 1.8; 95% CI: 1.1, 2.8; $P < 0.05$) and back pain (OR 1.9; 95% CI: 1.1, 3.1; $P < 0.05$) were specific painful sites significantly associated with greater odds of recurrent falls. Participants with joint leg pain or back pain had 0.2 and 0.1 more recurrent falls respectively, although this was not statistically significant (Table A.3).

3.3. Association between pain characteristics and injurious falls

The presence of pain (OR: 1.8; 95% CI: 1.3, 2.5; $P < 0.001$) (Table 3) and joint leg pain (OR: 1.5; 95% CI: 1.1, 2.2; $P < 0.05$) (Table A.5) were significantly associated with greater odds of injurious falls in unadjusted models. After controlling for demographic and health-related variables, other risk factors were more indicative of injurious falls compared to both presence of pain and specific pain sites. These risk factors were predominantly markers of physical deconditioning such as older age, poor handgrip strength, and excellent or poor vision (Table 3 and Table A.5). Similar to recurrent falls, a U-shape relationship was observed between self-assessed vision and injurious falls, with self-assessed "good" eyesight being statistically significant.

3.4. Poor physical strength and depression as a mediator of pain characteristics and recurrent falls

To further clarify the mechanism between pain and different types of falls, we examined the mediating effect of physical strength (handgrip strength) and depression (CES-D score) on these relationships. Significant associations between pain characteristics and recurrent falls identified in the hurdle models were subsequently assessed in causal mediation models. Fig. 1 shows models assessing physical strength and depression as single mediators between pain characteristics and recurrent falls. The presence of pain and joint leg pain had significant direct effects on recurrent falls, and poor physical strength and depression partially mediated these relationships (Fig. 1A, 1B, 1C, 1D). Direct effects of back pain on recurrent falls were also significant, though poor physical strength showed no significant indirect effect on the back pain-recurrent fall relationship (Fig. 1E, 1F). Instead, only depression had significant indirect effects and partially mediated the relationship between back pain and recurrent falls (Fig. 1F).

3.5. Poor physical strength and depression as a mediator of pain characteristics and injurious falls

Fig. 2 shows models assessing physical strength and depression as

Table 1
Characteristics of participants who completed questionnaires in Wave I and II.

	Total (n = 2844) ¶	Non-Fallers (n = 2623)	Recurrent Fallers (n = 144)	P	Injurious Fallers (n = 166)	P
Age (years), Mean (SD)	72.1 (7.8)	71.8 (7.7)	74.4 (8.3)	***	75.2 (8.0)	***
Sex (female), n (%)	1562 (54.2%)	1398 (53.3)	88 (61.1)		104 (62.7)	*
Ethnicity, n (%)						
Chinese	2103 (72.9%)	1925 (73.4)	94 (65.3)	*	118 (71.1)	
Indian	278 (9.6%)	245 (9.3)	24 (16.7)		18 (10.8)	
Malay	503 (17.4%)	453 (17.3)	26 (18.1)		30 (18.1)	
Education Level, n (%)						
No formal education	1011 (35.1%)	903 (34.4)	51 (35.4)		77 (46.4)	
Primary	1046 (36.3%)	950 (36.2)	54 (37.5)		58 (34.9)	
Secondary	622 (21.6%)	576 (22.0)	30 (20.8)		24 (14.5)	
Junior College / Poly	116 (4.0%)	110 (4.2)	4 (2.8)		4 (2.4)	
Vocational / ITE	5 (0.2%)	5 (0.2)	0 (0.0)		0 (0.0)	
University and above	78 (2.7%)	73 (2.8)	5 (3.5)		3 (1.8)	
Don't know / Can't remember	6 (0.2%)	6 (0.2)	0 (0.0)		0 (0.0)	
Housing Type, n (%)						
1–2 room HDB	243 (8.4%)	219 (8.3)	14 (9.7)		15 (9.0)	
3 room HDB	785 (27.2%)	728 (27.8)	30 (20.8)		37 (22.3)	
4–5 room HDB and Private Housing	1856 (64.4%)	1676 (63.9)	100 (69.4)		114 (68.7)	
Living arrangements, n (%)						
Living alone	184 (6.4%)	166 (6.3)	9 (6.2)		11 (6.6)	**
With child and spouse	1143 (39.6%)	1051 (40.1)	49 (34.0)		56 (33.7)	
With child only	886 (30.7%)	779 (29.7)	58 (40.3)		70 (42.2)	
With others only (incl maid)	133 (4.6%)	120 (4.6)	9 (6.2)		9 (5.4)	
With spouse only	538 (18.7%)	507 (19.3)	19 (13.2)		20 (12.0)	
Vision status, n (%)						
Excellent	310 (10.7%)	273 (10.4)	24 (16.7)	**	24 (14.5)	**
Very Good	397 (13.8%)	361 (13.8)	21 (14.6)		22 (13.3)	
Good	1560 (54.1%)	1448 (55.2)	59 (41.0)		69 (41.6)	
Fair	499 (17.3%)	439 (16.7)	32 (22.2)		41 (24.7)	
Poor	118 (4.1%)	102 (3.9)	8 (5.6)		10 (6.0)	
	Total (n = 2844)	Non-Fallers (n = 2623)	Recurrent Fallers (n = 144)	P	Injurious Fallers (n = 166)	P
Hearing status, n (%)						
Excellent	492 (17.1%)	441 (16.8)	29 (20.1)	**	35 (21.1)	*
Very Good	399 (13.8%)	357 (13.6)	30 (20.8)		19 (11.4)	
Good	1529 (53.0%)	1416 (54.0)	54 (37.5)		75 (45.2)	
Fair	341 (11.8%)	302 (11.5)	25 (17.4)		24 (14.5)	
Poor	123 (4.3%)	107 (4.1)	6 (4.2)		13 (7.8)	
Presence of Pain, n (%)						
No	1740 (60.3%)	1629 (62.1)	51 (35.4)	***	79 (47.6)	***
Yes	1144 (39.7%)	994 (37.9)	93 (64.6)		87 (52.4)	
Single/Multi-site Pain, n (%)						
No pain	1740 (60.3%)	1629 (62.1)	51 (35.4)	***	79 (47.6)	***
1 pain site	560 (19.4%)	497 (18.9)	36 (25.0)		38 (22.9)	
At least 2 pain sites	584 (20.2%)	497 (18.9)	57 (39.6)		49 (29.5)	
Number of Pain Sites, Mean (SD)	0.72 (1.1)	0.7 (1.1)	1.3 (1.3)	***	1.0 (1.2)	**
CES-D, n (%)°						
Depression: No	2296 (79.6%)	2111 (80.5)	102 (70.8)	*	117 (70.5)	*
Depression: Yes	415 (13.9%)	364 (13.9)	28 (19.4)		33 (19.9)	
Number of diseases						
No chronic diseases	599 (20.8%)	561 (21.4)	20 (13.9)	**	25 (15.1)	
1–3 chronic illness	1980 (68.7%)	1796 (68.5)	99 (68.8)		120 (72.3)	
More than 4 chronic diseases	305 (10.6%)	266 (10.1)	25 (17.4)		21 (12.7)	
Polypharmacy, (Mean, SD)	1.3 (1.2)	1.2 (1.2)	1.6 (1.4)	**	1.5 (1.3)	*
ADL Difficulties						
No ADL difficulties	2695 (93.4%)	2465 (94.0)	124 (86.1)	***	146 (88.0)	**
At least one ADL difficulty	189 (6.6%)	158 (6.0)	20 (13.9)		20 (12.0)	
IADL Difficulties						
No IADL difficulties	2474 (85.8%)	2283 (87.0)	106 (73.6)	***	119 (71.7)	***
At least one IADL difficulty	410 (14.2%)	340 (13.0)	38 (26.4)		47 (28.3)	
Handgrip Strength (Dominant hand), Mean (SD)	20.7 (7.9)	21.0 (7.9)	17.7 (6.9)	***	17.8 (7.0)	***

Students' t-test and chi-square test were performed to characterize group differences between fallers and non-fallers for continuous and discrete variables respectively. Fisher exact test was employed for discrete variables when the expected cell count was < 5. CES-D: Center for Epidemiologic studies for Depression. ADL: Activities of daily living. IADL: Independent activities of daily living. *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$. ¶Contains all participants including non-fallers, injurious fallers and recurrent fallers. 49 (1.7%) participants are both recurrent and injurious fallers, hence total numbers might not add up to 2884.
°Contains a missing value, thus percentages might not add up to 100%.

single mediator models in the context of injurious falls. Interestingly, similar to recurrent falls, the presence of pain in older adults had a significant direct effect on injurious falls, with poor physical strength having a significant mediation effect on this relationship (Fig. 2A). However, poor physical strength did not mediate the direct effects between joint leg pain and injurious falls (Fig. 2C). The mediating effect of depression on pain characteristics and recurrent falls was not statistically significant as well (Fig. 2B, 2D).

Table 2
Association between the presence of pain and recurrent falls.

	Part 1 (Binary Logit Model): Odds ratios predicting recurrent falls			Part 2 (Truncated Negative Binomial Model): Coefficients for factors associated with frequency of recurrent falls in the past year among those who had recurrent falls		
	Odds ratio	95% CI	P	Coefficient	95% CI	P
Presence of pain (Ref: No pain)						
Yes	2.8	(1.8, 4.4)	0.00***	0.4	(0.0, 0.8)	0.05*
Dominant Handgrip Strength	1.0	(0.9, 1.0)	0.02*	0.00	(−0.03, 0.03)	1.00
Ethnicity (Ref: Chinese)						
Indian	2.4	(1.4, 4.0)	0.00***	−0.2	(−0.6, 0.2)	0.34
Malay	1.3	(0.8, 2.3)	0.33	−0.5	(−0.9, −0.1)	0.02*
Self-assessed vision (Ref: Excellent)						
Very Good	0.5	(0.2, 0.9)	0.02*	−0.3	(−0.8, 0.2)	0.27
Good	0.3	(0.2, 0.6)	0.00***	−0.4	(−0.8, −0.1)	0.03*
Fair	0.5	(0., 0.92)	0.03*	−0.1	(−0.6, 0.3)	0.61
Poor	0.4	(0.1, 1.1)	0.08	−0.2	(−0.9, 0.5)	0.62

Analyses was adjusted for demographic and health-related variables including age, handgrip strength, ethnicity, housing type, living arrangements, depression status, self-assessed vision, comorbidities and the number of medications taken. Only statistically significant covariates were presented. Full table with all covariates are presented in Table A.2. CI: Confidence interval. *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$.

Table 3
Association between the presence of pain and injurious falls.

	Model 1 Odds Ratio	95% CI	P	Model 2 Odds Ratio	95% CI	P
Presence of pain (Ref: No pain)						
Yes	1.8	(1.3, 2.5)	0.00***	1.5	(1.0, 2.2)	0.06
Age				1.0	(1.0, 1.1)	0.02*
Dominant Handgrip Strength				1.0	(0.9, 1.0)	0.03*
Self-assessed vision (Ref: Excellent)						
Very Good				0.8	(0.3, 0.9)	0.17
Good				0.5	(0.6, 1.9)	0.02*
Fair				0.6	(0.3, 1.9)	1.0
Poor				1.0	(0.7, 1.9)	0.58

Model 1: Unadjusted logistic regression model; Model 2: Adjusted for demographic and health-related variables including age, handgrip strength, ethnicity, housing type, living arrangements, depression status, self-assessed vision, comorbidities and the number of medications taken. Only statistically significant covariates were presented. Full table with all covariates are presented in Table A.4. CI: Confidence interval. *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$.

4. Discussion

The presence of pain and specific painful sites were significantly associated with recurrent falls, and this relationship was partially mediated by poor physical strength and depression. Pain characteristics were significantly associated with injurious falls only in unadjusted models, and mediation analyses demonstrated only poor physical strength partially mediating this relationship.

4.1. Recurrent falls

Results from the study found significant direct effects between pain and recurrent falls. These findings are consistent with a previous systematic review suggesting that the presence of pain was indicative of recurrent falls (Stubbs et al., 2014). In our study, participants with joint leg pain and back pain were more likely to experience recurrent falls. Older adults with lumbar pain were found to have a loss of flexibility and muscle weakness in the trunk or extremities (Kato et al., 2019).

Results also demonstrate the causal relationship between pain characteristics and recurrent falls, mediated by poor physical strength. Pain, mediated by muscle weakness can result in impaired function of the musculoskeletal system, translating to poor mobility, gait and balance contributing to recurrent falls (Moreland et al., 2004; Dixe et al., 2021). Muscle weakness could arise from the direct effect of pain on muscles as well (Mense, 2008). Consequently, older adults with pain tend to restrict physical activity, which can result in greater muscle loss and strength. This perpetual physical deconditioning may result in a greater risk of falls.

Pain, mediated by depression, is another causal mechanism for recurrent falls identified in this study. Pain and depression could interfere with executive function and attention, resulting in the poor ability to respond to falls appropriately (Iaboni & Flint, 2013). Individuals with depression walked slower, spent more time with both feet on the ground and have decreased push-off (Hausdorff et al., 2004), compounding the existing mobility issues present among older adults with pain. In addition, depression has been shown to be an immediate consequence of pain and may increase sensitivity or reduce tolerance to pain (Chou, 2007; Meagher et al., 2001). Studies have identified the association between pain and the fear of falling (Mat et al., 2020; Patel et al., 2014). The psychological squeal as a consequence of falls have been established, and depression may be modulating the relationships in fear of pain, fear of falling, avoidance activities and physical deconditioning (Deshpande et al., 2008; Hadjistavropoulos et al., 2007).

4.2. Recurrent injurious falls

A U-shape relationship was observed between self-assessed vision and both recurrent and injurious falls separately. This indicates that older adults with excellent and poor eyesight have a greater susceptibility to high-risk falls. Activity limitation due to fear of falling among older adults with visual impairment may be a compensatory strategy protective against falls (Wang et al., 2012). A similar U-shape relationship between physical activity and the rate of falls has been observed in a previous study (Lu et al., 2020). This indicates that high physical activity, especially among older adults with excellent eyesight; and physical inactivity, among those with poor eyesight, increases the risk of falls among older adults (Lu et al., 2020).

Interestingly, similar to that with recurrent falls, the presence of pain in older adults has direct effects on injurious falls and this pathway is mediated by poor physical strength. From adjusted regression models, markers of physical deconditioning were more indicative of injurious falls compared to the presence of pain. This is consistent with a recent prospective population-based study, where markers of comorbidity such as physical and cognitive frailty, were associated with increased recurrent falls and fall-related injuries such as fractures (de Vries et al., 2013; Ensrud et al., 2007). Furthermore, though small in percentage, 49 (1.7%) participants in the population experienced both recurrent *and* injurious falls.

These results may suggest the archetype of recurrent injurious fallers, where frailty may be both a consequence and a risk factor contributing to this type of fall. Due to the added complexities of

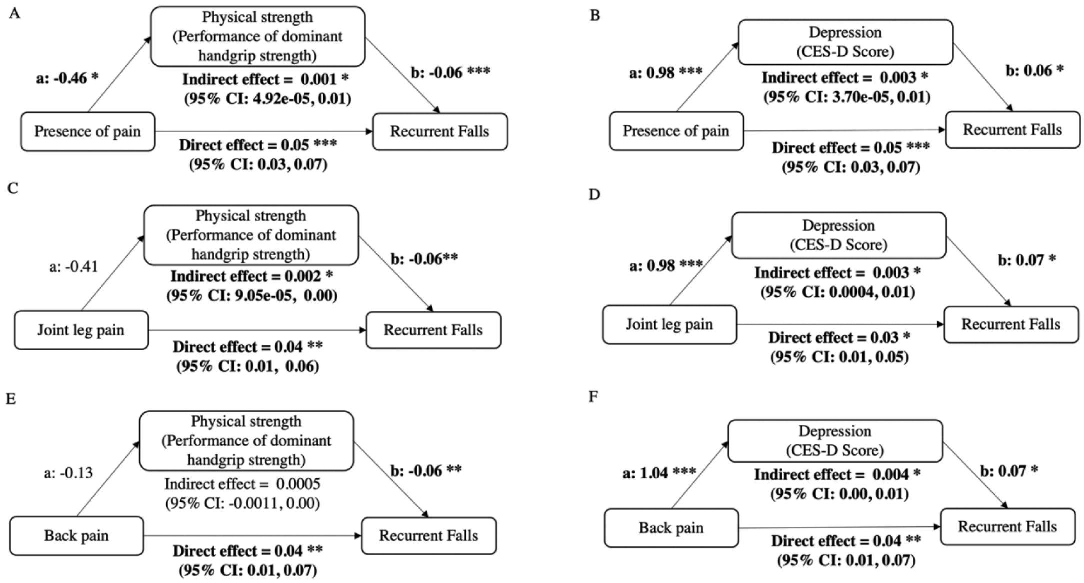

Fig. 1. Mediation analysis of the performance of physical strength and depression on the relationship between pain characteristics and recurrent falls. A: Single mediator model of physical strength (performance of dominant handgrip strength) on the relationship between the presence of pain and recurrent falls. B: Single mediator model of depression (CES-D) on the relationship the between presence of pain and recurrent falls. C: Single mediator model of physical strength on the joint leg pain-recurrent falls nexus. D: Single mediator model of depression on the joint leg pain-recurrent falls nexus. E: Single mediator model of physical strength on the back pain-recurrent falls nexus. F: Single mediator model of depression on the back pain-recurrent falls nexus. All models were adjusted for demographic and health-related variables. Standard coefficients were shown along with 95% confidence intervals. "a" is the linear regression coefficient of the pain-mediator association; "b" is the coefficient of the mediator-recurrent fall association. *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$.

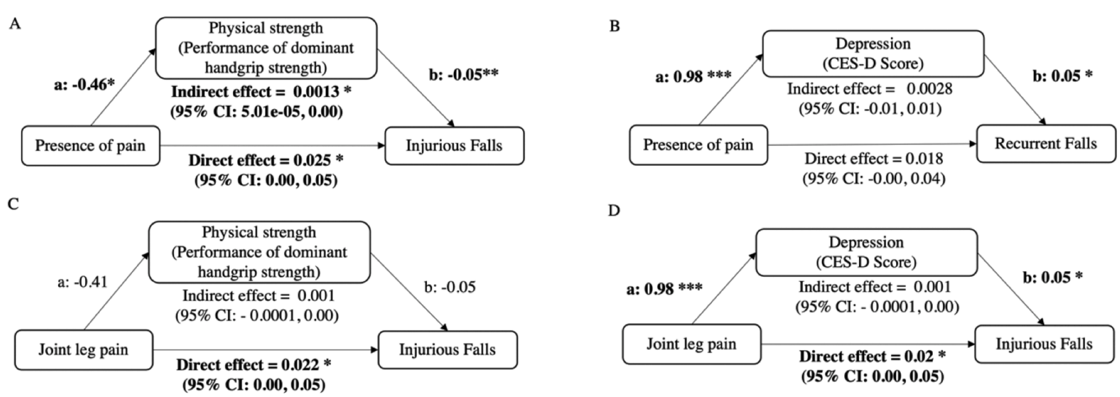

Fig. 2. Mediation analysis of the performance of physical strength and depression on the relationship between pain characteristics and injurious falls. A: Single mediator model of physical strength on the pain-injurious falls nexus. B: Single mediator model of depression on the pain-injurious falls nexus. C: Single mediator model of physical strength on the joint leg pain-injurious falls nexus. D: Single mediator model of depression on the joint leg pain-injurious falls nexus. All models were adjusted for demographic and health-related variables. Standard coefficients were shown along with 95% confidence intervals. "a" is the linear regression coefficient of the pain-mediator association; "b" is the coefficient of the mediator-recurrent fall association. *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$.

recurrent injurious falls, the identification of associated risk factors would be clinically meaningful for patient monitoring and care planning. Further research into the modifiable risk factors and mechanisms of recurrent injurious falls is warranted.

4.3. Injurious falls

Joint leg pain had significant direct effects on injurious falls in single mediation models. In a previous study, the increasing severity of knee pain was associated with a greater risk of falls and hip fracture (Arden et al., 2006). This is due to a combination of postural instability, quadriceps weakness and decreased proprioception (Kim et al., 2018; Hicks et al., 2020). Activity restriction due to severe knee pain will result in general deconditioning, increasing the risk of falls and fractures.

Old age, muscle weakness and poor vision were indicators of injurious falls as shown in the logistic regression analyses. Findings from the causal mediation analyses also indicated that physical strength and depression were not mediators of the pain-injurious nexus (Fig. 2B, 2C, 2D), indicating that their respective effects on injurious falls were independent of pain. Consistent with other studies (Lloyd et al., 2009; O'Loughlin et al., 1993), our findings demonstrate that injurious fallers were older than recurrent fallers and significantly older than non-fallers. Older age can result in age-associated changes in muscle strength and visual acuity (Patino et al., 2010). These processes may be responsible for the increased risk of injurious falls. Hence, age-related physiological changes, and physical deconditioning may result in an increased risk of injurious falls.

4.4. Clinical significance and implications

The results from our mediation analysis suggest that mechanisms involving poor muscle strength and depression, play a substantial role in underlying the relationship between pain and falls. This study also identified causal associations for different types of falls, demonstrating the heterogeneity of fallers in an older adult population.

This study calls greater attention to pain management among older adults at higher risk of falls. Findings from the mediation analyses demonstrate how joint and back pain have a direct effect on recurrent falls. Pain relief particularly at the joints of lower limbs may be effective in preventing recurrent falls as the effects of joint leg pain on recurrent falls are apparent in two pathways – both direct and mediating pathways. Assessment and management of joint leg and back pain in fall screening programmes should be incorporated as well. When doing so, physicians need to be aware of the possible differences in reporting styles among patients of different subgroups. A previous study reported ethnic differences in the perception of pain, with Chinese persons underreporting pain severity in comparison to Malays and Indians in Singapore (Chan et al., 2011). A multidisciplinary approach is recommended for pain management, which includes pharmacological treatments, psychological support, and physical rehabilitation (Kaye et al., 2010). Due to the similar multi-factorial management modalities for pain and falls, pain relief should be incorporated as components in multi-component fall prevention programmes.

The identification of partial mediators involved in the pain-fall nexus demonstrated a pressing need to manage these factors, especially for fallers with pre-existing pain characteristics. Psychotherapy, meditation other non-pharmacological approaches such as cognitive behavioral therapy should be employed in fall prevention interventions, focusing on addressing pain relief. Moreover, the combination of personalized strength training and physical rehabilitation at specific painful sites like the back or joint leg would be effective in managing pain and deteriorating physical function.

Lastly, different interventions should be recommended for different profiles of fallers. Strength training and addressing visual impairments would be vital for the prevention of injurious falls. Active eye screening services along with appropriate management of poor visual acuity should be included in fall prevention programmes as well.

4.5. Strengths and limitations

The strengths of this study include a large sample size from a multi-ethnic Asian community, as well as the prospective recording of fall events in Wave II. Standardized questionnaires were utilized for data collection in both Waves, enabling the comprehensive evaluation of mechanisms underlying pain and recurrent and injurious falls. This study has a few limitations. Firstly, we did not collect information on the use of antidepressants such as tricyclic antidepressants and selective serotonin reuptake inhibitors. Future research is needed to investigate these independent associations and mechanisms while controlling for antidepressant use. Potential recall bias may also lead to inaccuracies, however, validation studies have indicated that self-reported falls is a reliable tool to measure fall outcomes (Ganz et al., 2005; Hale et al., 1993). In a meta-analysis, patients with fall-related injuries requiring hospital care had better recall, greater percentage match with hospital records and high sensitivity (Ganz et al., 2005). Furthermore, details on pain such as whether it was neuropathic or nociceptive pain were not collected in this study. This information may be useful in shedding additional insight on pain aetiologies and could be useful in providing specific recommendations effective for different individuals.

5. Conclusions

In conclusion, we found poor physical strength and depression mediate the relationship between pain and recurrent falls. Poor physical strength partially mediates the effects of pain and injurious falls as well. However, the mediating effect of poor physical strength and depression was not observed between pain at specific sites and injurious falls. Our findings highlighted the differences between recurrent and injurious falls; where pain characteristics and mediators were better indicators of recurrent falls while markers of physical deconditioning were more indicative of injurious falls. These insights will be useful in identifying older adults most at risk for recurrent and injurious falls, and aid in the design of future fall prevention strategies for older adults in the community.

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Data availability statement

Data utilized for this study are available from the Centre for Ageing Research and Education (CARE). De-identified data can be made available upon reasonable request and permission from CARE.

CRediT authorship contribution statement

Vanessa Koh: Conceptualization, Methodology, Formal analysis, Writing – original draft. **David B. Matchar:** Writing – review & editing, Supervision, Funding acquisition. **Angelique Chan:** Writing – review & editing, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare no conflict of interest. Preliminary findings were presented in the 2022 International Alliance of Research Universities Aging, Longevity and Health Conference.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.archger.2023.105015.

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