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低风险老年人步行锻炼与跌倒关系的 Meta 分析

谭　恺[1,2],王军力[2],王玉龙[2]
(1. 福建师范大学体育学院,福建 福州 350117;
2. 怀化学院体育学院,湖南 怀化 418000)

摘　要:步行是老年人最主要的体力活动形式和被老年人普遍接受的体育锻炼方式,其具有诸多健康益处,但也存在潜在跌倒风险,明确跌倒风险是实现步行健康益处的必要前提。对于步行能力较弱的高风险老年人,步行导致跌倒率增加,但对于步行能力较强的低风险老年人,步行对其跌倒率的影响尚存争议。探析低风险老年人步行与跌倒的关系有助于明确老年人步行跌倒风险,确保获得步行健康益处。Meta 分析显示 12 项纳入研究无异质性,合并相对危险度 RR = 0.74,95% CI(0.66 – 0.83),$P < 0.001$,结果不存在发表偏倚。结果表明:低风险老年人步行有助于降低跌倒率,其原因在于低风险老年人对步行的跌倒暴露风险不敏感,而且能通过步行获得足够健康益处和预防跌倒的接种效应。步行可以作为预防低风险老年人跌倒的一种干预方式。

关键词:老年人;步行;跌倒;Meta 分析;步行能力
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The Relationship between Walking and Falling in the Elderly People with Low Risk: A Meta-analytic Review

TAN Kai[1,2], WANG Jun-li[2], WANG Yu-long[2]
(1. School of Physical Education and Sports Science of Fujian Normal University, Fuzhou 350117, China;
2. College of Physical Education of Huaihua University, Huaihua 418000, China)

Abstract: Physical activity plays an active role in facilitation of "healthy aging". Walking is not only the most important Physical activity, but also a popular exercise for elderly people. Although walking would bring substantial health benefits, it might have potential fall risk. The premise behind the health benefits is to realize and reduce the fall risk. Numerous studies have shown that the elderly people with high fall risk who have weak walking ability tend to fall in walking. However, for elderly people with low fall risk who have strong walking ability, the relationship between walking and fall remains controversial. Analyzing the relationship between the walking and falling in low risk elderly people should contribute to guarantee the health benefits of walking. Meta analysis show that 12 studies have no heterogeneity, pool relative risk for incidence of fall RR = 0.74, 95% CI (0.66 0.83), $P < 0.001$, and have no bias of publication. It was concluded that walking contributes to reducing the rate of fall in elderly people with low risk. Walking can be used as an intervention approach to prevention of falling for elderly people with low fall risk.

Key words: elderly people; walking; falling; Meta analysis; walking ability

《国家人口发展规划(2016—2030 年)》预计"2021—2030 年我国 60 岁及以上老年人口增长速度将明显加快,到 2030 年老年人将达到 25 % 左右"。面对老龄化程度不断加深趋势,"健康老龄化"成为个体和社会共同努力的迫切目标。体力活动对"健康老龄化"具有不可替代的促进作用,步行作为老年人最主要体力活动形式和被老年人普遍接受的体育锻炼方式,对老年人具有诸多健康益处,包括改善心血管、代谢、体成分和认知功能,提高有氧能力、延缓骨质流失、促进心理健康以及预防多种疾病和慢性

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第一作者简介:谭恺(1982—),男,四川眉山人,博士,讲师。研究方向:运动生物力学。

病[1-7]。基于步行活动水平(步行量和强度)与健康益处的剂量-反应关系[5-6],研究者提出有关步行强度、时间和步行量的步行建议[1,8,9]。然而,这些旨在健康促进和疾病防治的步行建议往往会忽视步行潜在的跌倒风险。跌倒是指突发的、不自主的、非故意的体位改变,倒在地面或更低平面上[10]。跌倒轻则引发老年人跌倒恐惧,致使其活动量减小从而难以实现步行的健康益处[11-13],重则导致伤残甚至死亡[10]。发达国家中,近 1/3 的社区老人每年至少发生一次跌倒[10,14],我国社区老人跌倒率为 11 % ~34 %[15,16]。鉴于跌倒的威胁性和高发性,明确并降低步行的跌倒风险是实现步行健康益处的必要前提。

老年人内在跌倒风险与机体系统的退行性或病理性变化密切相关。步行是神经系统、运动系统、感觉系统以及认知系统通过复杂交互而产生的行为,这些系统的功能状态决定步行能力高低。步行能力降低的典型表现——步速减慢[17-20],步态时空参数变异增大[21-25],步行动态稳定性降低[26-28]皆可导致跌倒风险升高,这表明步行能力是老年人跌倒风险的决定性因素,步行能力低则跌倒风险高,反之亦然。对于步行能力较低的高风险老年人,研究发现步行导致跌倒率升高[29-33];对于步行能力较高的低风险老年人,步行对跌倒风险的影响尚有不同结论[34-38]。此外,跌倒经历可诱发老年人跌倒恐惧和谨慎步态,从而降低体力活动水平,使其难以获得健康益处,进而导致机体系统功能和步行能力下降,形成"跌倒—体力活动减少—机体功能下降—跌倒"的恶性循环。明确低风险老年人步行与跌倒的关系有助于防范跌倒,尽可能推迟低风险老年人发展为高风险老年人的时间,对老年人跌倒预防和体力活动促进皆具重要意义。鉴于此,本文依据系统评价和 Meta 分析优先报告条目声明(PRISMA)对相关研究进行综述,探讨低风险老年人步行与跌倒的关系并分析原因,旨在为低风险老年人步行和跌倒预防提供参考,促进其获得步行的健康益处,助力"健康老龄化"。

1 资料与方法

1.1 资料来源

文献检索时间设定为 1995 年 1 月—2018 年 1 月。中文检索数据库为中国期刊全文数据库(CNKI),检索词为"跌倒"/"步行"/"社区老人"(居住社区是低风险老年人的基本条件);英文检索数据库有 PudMed,EBSCO - MEDLINE 和 Web of Science,检索词为"fall"/"walk"/"community dwelling elderly"。共获得文献 184 篇,其中英文 137 篇,中文 47 篇。

1.2 文献纳入与排除标准

文献纳入标准:(1)运动干预老年人跌倒的随机对照试验;(2)运动干预为步行或包含步行;(3)数据结果包括跌倒人数(人次)、跌倒率或相对危险度(Relative Risk,RR = 干预组跌倒率/对照组跌倒率);(4)研究样本为低跌倒风险老年人。依据先前研究[32,37],将低风险老年人界定为能独立完成日常生活活动,没有严重肌骨和认知系统病症以及精神类药物史的社区老年人,且不符合下述条件或者仅符合其中 1 项:a. 最近 1 年内发生跌倒损伤;b. 年龄大于 75 岁;c. 平衡能力差——单腿站立小于 10 秒;d. 活动能力不足——10 个阶梯或 400 米步行需要休息。

文献排除标准:(1)不符合上述纳入标准者;(2)综述文献和学位论文。

1.3 文献筛选与资料提取

由两位评价者独立进行文献筛选和资料提取,并交叉核对,如遇分歧,则通过讨论解决。按照系统综述和 Meta 分析的要求整理、核对数据,建立数据库。将文献数据统一整理为:基本资料——作者、年限;研究特征——样本量、样本年龄、干预和对照方案、随访时间、相对危险度(95% CI)。并对纳入文献进行方法学质量评估。

1.4 统计分析

利用 STATA11.0 软件对数据进行统计学分析:(1)对纳入研究进行异质性检验以确定分析模型;(2)选用相对危险度(Relative Risk,RR = 干预组跌倒率/对照组跌倒率)及其 95 % 置信区间(95 % CI)作为合并效应值进行分析;(3)利用 Begg 秩相关检验和 Egger 线性回归法进行发表偏倚检验。

2 结果

2.1 纳入研究筛选流程

依据检索要求共获得文献 184 篇,然后根据纳入标准和排除标准,最终纳入文献 12 篇[39-50],纳入流程见图 1。

2.2 纳入研究的方法学质量评价

采用 Cochrane 偏倚风险评估工具(评估内容包括选择性偏倚、测量偏倚、实施偏倚、报告偏倚)对 12

项纳入文献进行方法学质量评估,其中 8 项 A 级(发生偏倚的可能性较低);3 项 B 级(中度可能性发生偏倚);1 项 C 级(发生偏倚可能性较大)。整体上看,纳入研究的方法学质量较高,发生偏倚风险的可能性较小,详见表 1。

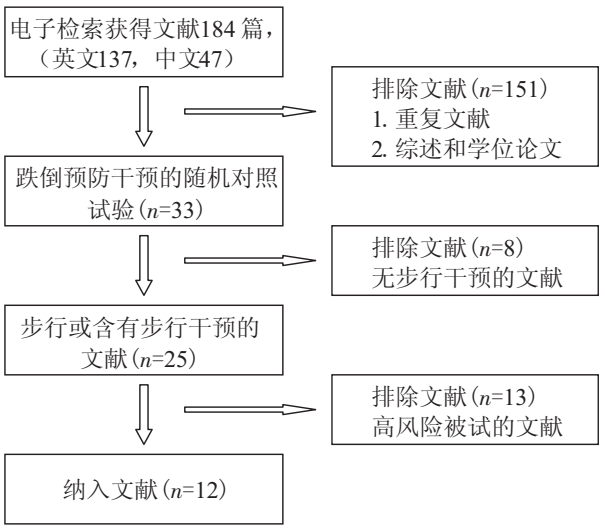

图 1　纳入文献流程图

2.3　纳入研究的资料汇总

按照系统综述和 Meta 分析要求整理、核对数据,建立数据库,将纳入文献数据统一整理为:基本资料——作者、年限,研究特征——样本量、样本年龄、干预和对照方案、随访时间、相对危险度(95 % 置信区间)。纳入研究 12 项,其中一项研究[43]包含两项随机对照试验,故共计 13 项随机对照试验,纳入样本 3 527 人,具体研究信息见表 2。

2.4　Meta 分析结果

采用 STATA11.0 统计软件对 12 项研究(纳入样本 3 527 人)进行 Meta 分析,选用相对危险度(Relative Risk,RR = 干预组跌倒率/对照组跌倒率)及其 95 % 置信区间(95 % CI)作为合并效应值。异质性检验显示($P = 0.719$,$I^2 = 0.0$ %),无统计学异质性,故采用固定效应模型分析。森林图(图 2)显示 $RR = 0.74$,95 % CI(0.66 – 0.83),$P < 0.001$,可见干预组和对照组的跌倒率差异具有统计意义,干预组发生跌倒的危险性显著低于对照组,表明步行能降低 26 % 跌倒率。

表 1　纳入研究的方法学质量评估表

研究	1 随机方法	2 分配隐藏	3 盲法	4 失访/退出	5 选择性 报告	质量等级
Campbell 1999[39]	L	L	U	L	L	A
Campbell 1997[40]	L	L	U	L	L	A
Cerny 1998[41]	L	L	U	L	L	A
Ebrahim 1997[42]	L	U	U	H	L	B
Illiffe 2014[43]	L	L	U	L	L	A
Korpelainen 2006[44]	L	L	U	U	L	B
Lord 1995[45]	L	L	U	L	L	A
Madureira 2007[46]	L	L	U	L	L	A
Means 2005[47]	L	U	U	L	H	C
Okubo 2016[48]	L	L	U	L	L	A
Robertson 2001[49]	L	L	U	L	L	A
Smulders 2010[50]	U	U	U	L	L	B

注:5 项指标中,L 代表低风险;U 代表不清楚;H 代表高风险。质量等级 A:4 项及以上指标为低风险 L,表示低度偏倚风险;等级 B:2 或 3 项指标为低风险 L,表示中度偏倚风险;C:1 项指标为高风险 H,或者少于 1 项低风险 L,表示高度偏倚风险

由图 3 可知,漏斗图对称,因此纳入的文献可能不存在发表偏倚。同时 Begg 秩相关检验所得 $P = 0.246$,Egger 线性回归法所得 $P = 0.186$,两种检验均无统计学意义,提示不存在发表偏倚。

表 2 纳入研究信息汇总表

序号	研究	样本	年龄	随访(月)	干预组	对照组
2	Campbell 1999[39]	152(女)	84 ± 3	24	步行 * ,SBF	日常生活
1	Campbell 1997[40]	233(女)	84 ± 3	12	步行 * ,SBF	日常生活
3	Cerny 1998[41]	28(男)	71 ± 4	6	快走,BFA	日常生活
4	Ebrahim 1997[42]	165(女)	66 ± 8	24	快走	日常生活
5	Illiffe 2014[43]	845(男女)	68 – 79	12	步行,SBF	日常生活
	Illiffe 2014[43]	869(男女)	68 – 79	12	步行,SB	日常生活
6	Korpelainen 2006[44]	160(女)	73 ± 1	30	步行,SB	日常生活
7	Lord 1995[45]	197(女)	72 ± 5	12	快走,SBFA	日常生活
8	Madureira 2007[46]	66(女)	73 ± 5	12	步行 * ,SB	日常生活
9	Means 2005[47]	338(男女)	≥65	6	步行,SBA	日常生活
10	Okubo 2016[48]	90(男女)	70 ± 4	16	步行	力量、平衡与太极
11	Robertson 2001[49]	240(男女)	81 ± 5	18	步行 * ,SB	日常生活
12	Smulders 2010[50]	144(男女)	75 ± 5	12	步行 * ,SBA	日常生活

注:步行 * —Otago(奥塔戈)运动中的步行锻炼和行走练习;S—力量练习(Strength);
B—平衡练习(Balance);F—柔韧练习(Flexibility);A—有氧能力练习(Aerobic endurance)

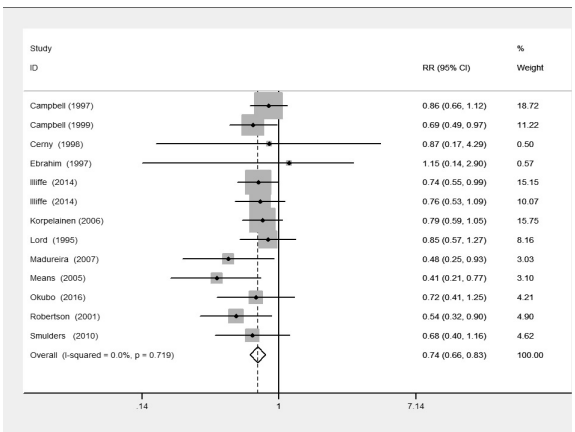

图 2 干预组和对照组 Meta 分析森林图

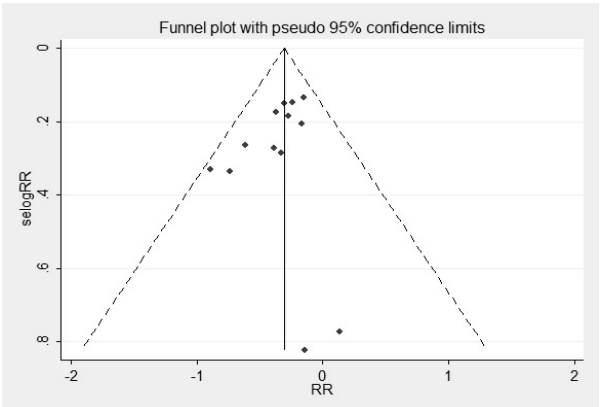

图 3 干预组和对照组 Meta 分析漏斗图

3 讨论

对 12 项纳入文献的 Meta 分析显示 $RR = 0.74$, 95 % CI(0.66 ~ 0.83), $P < 0.001$,结果无发表偏倚,表明低风险老年人步行可降低 26% 跌倒率,步行有助于降低跌倒风险和预防跌倒。该结果与 Brodie(2017)[51]、Mertz(2010)[52]、Heesch(2008)[53]、Chang(2004)[54]、Province(1995)[35]的发现一致。Brodie(2017)[51]发现活动能力强的低风险老年人跌倒率低。Mertz(2010)[52]通过大样本跟踪调查发现,健康状况较好且有氧能力较高的低风险老年人步行有助于降低跌倒率。Heesch(2008)[53]对社区老年女性为期 3 ~ 6 年的大样本调查同样发现类似结果,步行能力较强且活动量较大的低风险老年女性表现出低跌倒率。Chang(2004)[54]和 Province 等(1995)[35]的综述显示对步速较高的低风险老年人进行步行干预可降低其跌倒风险。此外,Okubo(2015)[32]用 7 项危险因素评估跌倒风险,发现高风险老年人(2 项及以上危险因素)步行与跌倒率升高相关,而低风险老年人(少于 2 项危险因素)步行与跌倒率降低相关。Hill(2002)[55]发现,对于住院和需要长期护理的高风险老人,步行会增加其跌倒风险,对于一般社区

老人,步行则可降低跌倒风险。由此可见,步行与跌倒的关系取决于老年人的跌倒风险水平,本 Meta 分析的纳入研究以低风险老年人为主,数据分析显示步行有助于降低跌倒率和预防跌倒。

低风险老年人步行有助于降低跌倒率的原因有三。首先,步行能力较强的老年人对步行的跌倒暴露风险不敏感。步行环境的潜在危险因素(如路面湿滑、障碍物)会增加跌倒风险,而且步行引发疲劳同样会增加跌倒风险[56]。故通常认为老年人步行伴随跌倒暴露风险。然而,低风险老年人步行的动态稳定性与适应性较好[51,57],并具有较强有氧能力[52],不仅能在一定程度上抵御环境因素所致的失衡,而且能避免疲劳或减轻疲劳程度,因而对一定程度的跌倒暴露风险并不敏感,即低风险老年人适当步行并不会导致跌倒风险升高。其次,步行能力较强的老年人能通过步行获得足够健康益处以降低跌倒风险。步行活动水平与健康益处具有剂量 - 反应关系,一定的步行活动水平才能产生显著健康益处。低风险老年人较强的步行能力可确保其达到足够的步行活动水平(如 >3000METs/周),以改善运动系统、感觉系统和认知系统功能,从而改善或提高步行能力,进而降低跌倒风险。最后,步行能力较强的老年人可从步行中获得预防跌倒的接种效应。步行的动态平衡由身体质心与支撑面的映射关系决定(相对位置和速度),二者关系突破稳定极限(Stability Limits)则发生跌倒[58]。当步行中的突发干扰(溜滑或磕绊)导致质心与支撑面的相对关系发生急剧变化而失衡时,中枢神经系统会自发产生相应动作来调节身体姿势以恢复质心和支撑面的稳定关系(动态平衡)。增强这种自发调节能力有助于减少由步行干预所致的跌倒。研究发现,包含少量溜滑干扰的步行训练能促使老年人对干扰产生适应性:中枢神经系统调节动态平衡的动作控制策略转变——从完全依赖反馈控制的策略转变为由前馈控制主导的策略,从而提高对失衡的应变速度[59];稳定极限的内部表征得到调适或更新以提高动态平衡的容错性[60]。这些适应性变化可有效改善并增强老年人对干扰失衡的自发调节能力,从而降低跌倒率[61-63]。更重要的是,老年人通过干预训练获得的适应性(得以改善和增强的调节能力)可保持 6~12个月[63-64],对跌倒具有显著预防效果,表明步行干预经历可产生预防跌倒的接种效应。步行能力较强的低风险老年人有更多机会经历步行干预且不致发生跌倒,通过干预经历产生适应性(改善调节失衡的动作策略;调适或更新稳定极限的内部表征),增强动态平衡的调节能力,获得预防跌倒的接种效应。

由此可见,步行能力较强的低风险老年人步行有助于降低跌倒率和预防跌倒,原因在于此类老年人一者对步行跌倒暴露风险不敏感,二者能达到足够的步行活动水平以获得足够健康益处从而改善步行能力并降低跌倒风险,三者可从步行中获得预防跌倒的接种效应。

4　研究展望

本 Meta 分析显示低风险老年人步行有助于降低跌倒率,表明步行有望成为预防低风险老年人跌倒的有效干预方式。然而,当前单以步行作为预防干预的研究较少,步行预防跌倒的独立效应有待进一步明确。对此,未来可开展更多低风险老年人步行预防跌倒的随机对照研究,以进一步确定步行的防跌效果。

纳入分析的 12 篇文献中,大多数研究选择了与老年人步行能力相适应的步行活动方案和活动水平(量和强度),可见,准确评估老年人步行能力是设计低风险步行方案的必要步骤。然而,常规的跌倒危险因素指标和站立平衡测试难以准确评估低风险老年人的步行跌倒风险。为此,后续研究可通过分析步态的时空参数变异性、日常步行数据(三轴加速度计)以及干扰状况下的步行动态平衡特征,以准确评估老年人跌倒风险从而提供更具针对性的步行建议与方案。

5　结论

低风险老年人步行有助于降低跌倒率。原因在于:具有较强步行能力的低风险老年人对步行的跌倒暴露风险不敏感;他们能达到适度的步行活动水平以获得足够的健康益处;在步行中产生预防跌倒的接种效应以提高抗外部干扰的动态平衡调节能力。步行可以作为预防低风险老年人跌倒的一种干预方式。

参考文献

[1] MEDICINE A C O S, CHODZKO - ZAJKO W J, PROCTOR D N, et al. Exercise and Physical Activity for Older Adults[J]. *Medicine & Science in Sports & Exercise*, 2009, 41(6): 992-1008.

[2] MORRIS J N, HARDMAN A E. Walking to Health[J]. *Sports Medicine*, 1997, 23(5): 306-332.

[3] HÖRDER H, SKOOG I, FRÄNDIN K. Health-related quality of life in relation to walking habits and fitness: a population-based study of 75-year-olds[J]. *Quality of Life Research*, 2013, 22(6): 1213-1223.

[4] BOUAZIZ W, VOGEL T, SCHMITT E, et al. Health benefits of aerobic training programs in adults aged 70 and over: a systematic review[J]. *Arch Gerontol Geriatr*, 2017, 69: 110-127.

[5] BARENGO N C, ANTIKAINEN R, BORODULIN K, et al. Leisure-Time Physical Activity Reduces Total and Cardiovascular Mortality and Cardiovascular Disease Incidence in Older Adults[J]. *Journal of the American Geriatrics Society*, 2016, 65(3): 504-510.

[6] KYU H H, BACHMAN V F, ALEXANDER L T, et al. Physical activity and risk of breast cancer, colon cancer, diabetes, ischemic heart disease, and ischemic stroke events: systematic review and dose-response meta-analysis for the Global Burden of Disease Study 2013[J]. *Bmj*, 2016, 354: i3857.

[7] DIEHR P, HIRSCH C. Health Benefits of Increased Walking for Sedentary, Generally Healthy Older Adults: Using Longitudinal Data to Approximate an Intervention Trial[J]. *J Gerontol A Biol Sci Med Sci*, 2010, 65(9): 982-989.

[8] CHOI B C K, PAK A W P, CHOI J C L, et al. Daily step goal of 10,000 steps: a literature review[J]. *Clinical & Investigative Medicine Médecine Clinique Et Experimentale*, 2007, 30(3): 146-151.

[9] TUDORLOCKE C, CRAIG C L, AOYAGI Y, et al. How many steps/day are enough? For older adults and special populations[J]. *International Journal of Behavioral Nutrition & Physical Activity*, 2011, 8(1): 80.

[10] ORGANIZATION W H. WHO global report on falls prevention in older age[R]. 2007.

[11] AUAIS M, ALVARADO B, GUERRA R, et al. Fear of falling and its association with life-space mobility of older adults: a cross-sectional analysis using data from five international sites[J]. *Age & Ageing*, 2017, 46(3): 459-465.

[12] KIM D, GEERT C, GUY V, et al. Fear-related avoidance of activities, falls and physical frailty. A prospective community-based cohort study[J]. *Age & Ageing*, 2004, 33(4): 368-373.

[13] LI F, FISHER K J, HARMER P, et al. Fear of falling in elderly persons: association with falls, functional ability, and quality of life[J]. *J Gerontol B Psychol Sci Soc Sci*, 2003, 58(5): 283-290.

[14] TINETTI M E, SPEECHLEY M, GINTER S F. Risk factors for falls among elderly persons living in the community[J]. *N Engl J Med*, 1988, 319(26): 1701-1707.

[15] MARCELLA MUN-SAN K, CLOSE J C T, WONG A K W, et al. Falls incidence, risk factors, and consequences in Chinese older people: a systematic review[J]. *Journal of the American Geriatrics Society*, 2011, 59(3): 536-543.

[16] 姜玉, 夏庆华, 胡嘉, 等. 上海市长宁区老年人跌倒伤害流行病学及疾病负担研究[J]. 中华疾病控制杂志, 2013, 17(2): 134-137.

[17] CALLISAYA M L, BLIZZARD L, , MCGINLEY J L, et al. Risk of falls in older people during fast-walking--the TASCOG study[J]. *Gait & Posture*, 2012, 36(3): 510-515.

[18] KAN G A V, ROLLAND Y, ANDRIEU S, et al. Gait speed at usual pace as a predictor of adverse outcomes in community-dwelling older people an International Academy on Nutrition and Aging (IANA) Task Force[J]. *Journal of Nutrition Health & Aging*, 2009, 13(10): 881-889.

[19] MONTERO-ODASSO M, SCHAPIRA M, SORIANO E R, et al. Gait velocity as a single predictor of adverse events in healthy seniors aged 75 years and older[J]. *J Gerontol A Biol Sci Med Sci*, 2005, 60(10): 1304-1309.

[20] QUACH L, GALICA A M, JONES R N, et al. The Non-linear Relationship between Gait Speed and Falls: The MOBILIZE Boston Study[J]. *Journal of the American Geriatrics Society*, 2011, 59(6): 1069-1073.

[21] HAMACHER D, SINGH N B, VAN DIEëN J H, et al. Kinematic measures for assessing gait stability in elderly individuals: a systematic review[J]. *Journal of the Royal Society Interface*, 2011, 8(65): 1682-1698.

[22] IHLEN E A, WEISS A, BECK Y, et al. A comparison study of local dynamic stability measures of daily life walking in older adult community-dwelling fallers and non-fallers[J]. *Journal of Biomechanics*, 2016, 49(9): 1498-1503.

[23] KÖNIG N, TAYLOR W R, ARMBRECHT G, et al. Identification of functional parameters for the classification of older female fallers and prediction of first-time' fallers[J]. *Journal of the Royal Society Interface*, 2014, 11(97): 0353.

[24] MORTAZA N, ABU OSMAN N A, MEHDIKHANI N. Are the spatio-temporal parameters of gait capable of distinguishing a faller from a non-faller elderly? [J]. *European Journal of Physical & Rehabilitation Medicine*, 2014, 50(6): 677-691.

[25] SVOBODA Z, BIZOVSKA L, JANURA M, et al. Variability of spatial temporal gait parameters and center of pressure displacements during gait in elderly fallers and nonfallers: A 6-month prospective study[J]. *Plos One*, 2017, 12(2): e0171997.

[26] LOCKHART T E, SPAULDING J M, PARK S H. Age-related

slip avoidance strategy while walking over a known slippery floor surface[J]. *Gait & Posture*,2007,26(1):142-149.

[27] LOCKHART T E, WOLDSTAD J C, SMITH J L. Effects of age-related gait changes on the biomechanics of slips and falls[J]. *Ergonomics*,2003,46(12):1136-1160.

[28] WANG Y, ASAKA T, WATANABE K. Multi-muscle synergies in elderly individuals: preparation to a step made under the self-paced and reaction time instructions[J]. *Experimental brain research*,2013,226(4):463-472.

[29] CAMPBELL A J, M CLARE R, GROW S J, LA, et al. Randomised controlled trial of prevention of falls in people aged > or =75 with severe visual impairment: the VIP trial[J]. *Digest of the World Core Medical Journals*,2005,331:817.

[30] FABER M J, BOSSCHER R J, PAW M J C A, et al. Effects of Exercise Programs on Falls and Mobility in Frail and Pre-Frail Older Adults: A Multicenter Randomized Controlled Trial[J]. *Arch Phys Med Rehabil*,2006,87(7):885-896.

[31] GREEN J, FORSTER A, BOGLE S, et al. Physiotherapy for patients with mobility problems more than 1 year after stroke: a randomised controlled trial[J]. *Lancet*, 2002, 359 (9302):199-203.

[32] OKUBO Y, SEINO S, YABUSHITA N, et al. Longitudinal association between habitual walking and fall occurrences among community-dwelling older adults: analyzing the different risks of falling[J]. *Archives of Gerontology & Geriatrics*, 2015,60(1):45-51.

[33] SCHOENFELDER D P. A fall prevention program for elderly individuals. Exercise in long-term care settings[J]. *Journal of Gerontological Nursing*,2000,26(3):43-51.

[34] ELKHOURY F, CASSOU B, CHARLES M A, et al. The effect of fall prevention exercise programmes on fall induced injuries in community dwelling older adults[J]. *Bmj*,2013, 347:f6234.

[35] PROVINCE M A, HADLEY E C, HORNBROOK M C, et al. The effects of exercise on falls in elderly patients. A preplanned meta-analysis of the FICSIT Trials. Frailty and Injuries: Cooperative Studies of Intervention Techniques[J]. *Jama*,1995,273(17):1341-1347.

[36] SHERRINGTON C, TIEDEMANN A, FAIRHALL N, et al. Exercise to prevent falls in older adults: an updated meta-analysis and best practice recommendations[J]. *N S W Public Health Bull*,2011,22(3-4):78-83.

[37] SHERRINGTON C, WHITNEY J, SR, HERBERT R, et al. Effective exercise for the prevention of falls: a systematic review and meta-analysis[J]. *Journal of the American Geriatrics Society*,2008,56(12):2234-2243.

[38] ZHAO R, FENG F, WANG X. Exercise interventions and prevention of fall-related fractures in older people: a meta-analysis of randomized controlled trials[J]. *International Journal of Epidemiology*,2017,46(1):149-161.

[39] CAMPBELL A J, ROBERTSON M C, GARDNER M M, et al. Falls prevention over 2 years: a randomized controlled trial in women 80 years and older[J]. *Age & Ageing*,1999,28 (6):513-518.

[40] CAMPBELL A J, ROBERTSON M C, GARDNER M M, et al. Randomised controlled trial of a general practice programme of home based exercise to prevent falls in elderly women[J]. *Bmj British Medical Journal*,1997,315(7115): 1065-1069.

[41] CERNY K, BLANKS R, MOHAMED O, et al. The effect of a multidimensional exercise program on strength, range of motion, balance and gait in the well elderly[J]. *Gait & Posture*, 1998,7(2):185-186.

[42] EBRAHIM S,. , THOMPSON P W, BASKARAN V,. , et al. Randomized placebo-controlled trial of brisk walking in the prevention of postmenopausal osteoporosis[J]. *Age & Ageing*,1997,26(4):253-260.

[43] ILIFFE S, DENISE K, RICHARD M, et al. Multicentre cluster randomised trial comparing a community group exercise programme and home-based exercise with usual care for people aged 65 years and over in primary care[J]. *Health Technology Assessment*,2014,18(49):1-105.

[44] KORPELAINEN R, KEINäNEN-KIUKAANNIEMI S, HEIKKINEN J, et al. Effect of impact exercise on bone mineral density in elderly women with low BMD: a population-based randomized controlled 30-month intervention[J]. *Osteoporosis international : a journal established as result of cooperation between the European Foundation for Osteoporosis and the National Osteoporosis Foundation of the USA*,2006,17(1): 109-118.

[45] LORD S R, WARD J A, WILLIAMS P,. , et al. The effect of a 12-month exercise trial on balance, strength, and falls in older women: a randomized controlled trial[J]. *Journal of the American Geriatrics Society*,1995,43(11):1198-1206.

[46] MADUREIRA M M, TAKAYAMA L, GALLINARO A L, et al. Balance training program is highly effective in improving functional status and reducing the risk of falls in elderly women with osteoporosis: a randomized controlled trial[J]. *Osteoporosis International*,2007,18(4):419-425.

[47] MEANS K M, RODELL D E, O'SULLIVAN P S. Balance, mobility, and falls among community-dwelling elderly persons: effects of a rehabilitation exercise program[J]. *American Journal of Physical Medicine & Rehabilitation*,2005,84 (4):238-250.

[48] OKUBO Y, OSUKA Y, JUNG S, et al. Walking can be more effective than balance training in fall prevention among community-dwelling older adults [J]. *Geriatrics & Gerontology International*, 2016, 16(1): 118-125.

[49] ROBERTSON M C, GARDNER M M, DEVLIN N, . , et al. Effectiveness and economic evaluation of a nurse delivered home exercise programme to prevent falls. 2: Controlled trial in multiple centres[J]. *Bmj*, 2001, 322(7288): 697-701.

[50] SMULDERS E, WEERDESTEYN V, GROEN B E, et al. Efficacy of a short multidisciplinary falls prevention program for elderly persons with osteoporosis and a fall history: a randomized controlled trial [J]. *Archives of physical medicine and rehabilitation*, 2010, 91(11): 1705-1711.

[51] BRODIE M A, OKUBO Y, ANNEGARN J, et al. Disentangling the health benefits of walking from increased exposure to falls in older people using remote gait monitoring and multidimensional analysis [J]. *Physiological measurement*, 2017, 38(1): 45-62.

[52] MERTZ K J, LEE D C, SUI X, et al. Falls Among Adults : The Association of Cardiorespiratory Fitness and Physical Activity with Walking-Related Falls[J]. *American Journal of Preventive Medicine*, 2010, 39(1): 15-24.

[53] HEESCH K C, BYLES J E, BROWN W J. Prospective association between physical activity and falls in community-dwelling older women [J]. *J Epidemiol Community Health*, 2008, 62(5): 421-426.

[54] CHANG J T, MORTON S C, RUBENSTEIN L Z, et al. Interventions for the prevention of falls in older adults: systematic review and meta-analysis of randomised clinical trials [J]. *Bmj Chinese Edition*, 2004, 328(7441): 680-683.

[55] HILL-WESTMORELAND E, COM O, SOEKEN K, et al. A meta-analysis of fall prevention programs for the elderly: how effective are they? [J]. *Nursing Research*, 2002, 51(1): 1-8.

[56] HELBOSTAD J L, LEIRFALL S, MOENILSSEN R, et al. Physical Fatigue Affects Gait Characteristics in Older Persons[J]. *Journals of Gerontology*, 2007, 62(9): 1010-1015.

[57] BRODIE M A, LORD S R, COPPENS M J, et al. Eight-Week Remote Monitoring Using a Freely Worn Device Reveals Unstable Gait Patterns in Older Fallers [J]. *IEEE Transactions on Biomedical Engineering*, 2015, 62 (11): 2588-2594.

[58] PAI Y C, PATTON J. Center of mass velocity-position predictions for balance control [J]. *Journal of Biomechanics*, 1997, 30(4): 347-354.

[59] BHATT T, WENING J D, PAI Y C. Adaptive control of gait stability in reducing slip-related backward loss of balance [J]. *Experimental Brain Research*, 2006, 170(1): 61-73.

[60] WANG T Y, BHATT T, YANG F, et al. Generalization of motor adaptation to repeated-slip perturbation across tasks[J]. *Neuroscience*, 2011, 180(2): 85-95.

[61] BHATT T, YANG F, PAI Y C. Learning to resist gait-slip falls: long-term retention in community-dwelling older adults [J]. *Archives of Physical Medicine & Rehabilitation*, 2012, 93(4): 557-564.

[62] PAI Y C, TANVI B, FENG Y, et al. Perturbation training can reduce community-dwelling older adults´ annual fall risk: a randomized controlled trial[J]. *Journals of Gerontology*, 2014, 69(12): 1586-1594.

[63] PAI Y C, YANG F, BHATT T, et al. Learning from laboratory-induced falling: long-term motor retention among older adults[J]. *AGE*, 2014, 36(3): 1367-1376.

[64] LIU X, BHATT T, WANG S, et al. Retention of the "first-trial effect" in gait-slip among community-living older adults [J]. *Geroscience*, 2017, 39(1): 1-10.

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