Proceedings of the Human Factors and Ergonomics Society Annual Meeting
2023, Vol. 67(1) 7–13

DOI: 10.1177/21695067231192520
journals.sagepub.com/home/pro
Sage

Do Sensor-Based Interventions Differ from Traditional Physical Therapies in Improving Older Adults' Balance?

Qian MAO[1], Lisha YU[1], Jiaxin ZHANG[2], Fan YANG[3], and Hailiang WANG[1]

Abstract

Interventions using sensor technologies have the potential to facilitate balance improvement in clinical practice and, to some extent, are recommended as an alternative to traditional physical therapies. However, whether sensor-based technologies differ from traditional physical therapies in improving older adults' balance remains unclear. Our systematic review identified 25 randomized controlled trials for the meta-analysis. The findings showed that sensor-based interventions performed better than traditional physical therapies in improving balance performance (mean difference = -0.448s, $p < 0.001$). In subgroup analyses by dividing sensors into three categories (i.e., optical, perception, and wearable sensors), interventions using optical sensors were more effective than traditional physical therapies (mean difference = -0.681s, $p < 0.001$); while no significant differences were found for the interventions using perception sensors (mean difference = -0.226 s, p =0.106) and wearable sensors (mean difference = -0.490s, $p < 0.328$) as compared to traditional physical therapies.

Keywords

sensor-based intervention, traditional physical therapies, balance, older adults, meta-analysis

Introduction

Over the past few decades, human life expectancy has increased dramatically due to tremendous advances in technology and healthcare. Approximately one-sixth of the global population will be over 60 by 2025 (Chen et al., 2022). This rapid growth of the aging population inevitably increases the risk of individual healthcare and their economic burden. For example, one in three older adults over 65 falls at least once a year, contributing to 55.8% of accidental deaths in older adults (Osoba et al., 2019). Thirty percent of falls are accompanied by various injuries that impair older adults' physical health and mobility independence (Barker et al., 2015). These fall-related consequences significantly reduce the confidence and life quality of older adults. Moreover, according to the statistics, the costs of fall-related injuries ranked fifth in individual medical expenses (Haddad et al., 2019).

Balance deteriorates along with aging and has been increasingly highlighted as a significant fall risk factor (Soh et al., 2021). Many therapies to improve balance performance have been proposed in rehabilitation and clinical practice to prevent falls. Traditional physical therapy interventions, such as Pilates exercise, high-intensity strength training, and Otago exercise, are commonly used by physiotherapists to improve balance impairment and have proven effective (Merchant et al., 2021). However, the global shortage of professional therapists and devices severely limits older adults' access to timely and essential medical support, especially during pandemics. In recent years, with the rapid development of sensor technology and novel advances in analytical algorithms, sensor-based interventions that combine sensor technologies and physical therapies have been proposed to improve older adults' balance in the home environment (Unbehaun et al., 2018). For example, exergaming and virtual reality have been widely adopted in balance exercise and training programs (Truijen et al., 2022; Zhang et al., 2022). Although the effectiveness of sensor-based interventions and traditional physical therapies have been validated separately in previous research, few studies

[1]School of Design, The Hong Kong Polytechnic University, Hong Kong, Hong Kong
[2]Southern University of Science and Technology, Shenzhen, Guangdong, China
[3]Department of Electrical and Electronic Engineering, The Hong Kong Polytechnic University, Hong Kong, Hong Kong

Corresponding Author:
Hailiang WANG, Department of Electrical and Electronic Engineering, The Hong Kong Polytechnic University, 11 Yuk Choi Rd, Hung Hom, Hong Kong, Hong Kong.
Email: hailiang.wang@polyu.edu.hk

Table 1. The search terms.

AND	(wearable* OR sensor* OR acceler * OR gyro* OR magnetometer* OR camera* OR track* OR exergam* OR virtual reality OR VR OR augmented reality OR AR)
	(balanc* OR postur* OR gait OR walk* OR mobility)
	(old* OR elder* OR senior* OR aged OR geriatr* OR gerontol*)
	(train* OR program* OR exercise* OR intervention*)
	(random* OR randomized controlled trial* OR RCT*)

have systematically compared these two types of interventions on older adults' balance performance and further specify the type of sensors.

Therefore, we tried to fill this research gap by providing a comprehensive and reliable assessment of the performance of sensor-based interventions and traditional physical therapies in balance improvement. We also further sub-grouped the sensors to explore specific sensors' effectiveness. Thus, we conducted a meta-analysis study, which pooled results from multiple previous studies. The method can provide a more precise estimate of the effectiveness difference between sensor-based interventions and traditional physical therapy interventions. Specifically, we utilized the Timed Up and Go Test (TUG) for evaluating old adults' balance (Akin et al., 2021). Moreover, based on a previous study (Chen et al., 2022), we categorized the sensors into optical sensors (i.e., normally including Kinect, infrared sensors, and cameras), perception sensors (i.e., referring to the Wii balance board and force platforms), and wearable sensors (i.e., related to accelerometers, gyroscopes, and inertial sensors).

Methods

Search and Selection Strategy

This review study was registered on the PROSPERO platform (No.: CRD42022362817) and performed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Guidelines (Higgins et al., 2019). We initially screened six electronic databases for relevant articles from 1970 to 2022, including Academic Search Premier, Cumulative Index to Nursing and Allied Health Literature-Complete, Cochrane Central Register of Controlled Trials, MEDLINE, PubMed, and Web of Science. Table 1 presents the search terms we used in this study.

We included the studies meeting the following criteria: 1) randomized controlled trials (RCTs); 2) with interventions of sensor technologies and traditional physical therapies; 3) with outcomes for balance evaluation; 4) with older adults over an average age of 60 years; 5) published in peer-reviewed journals; 6) written in English. We excluded review articles, case studies, commentary letters, and studies with only qualitative analyses. We first identified the relevant articles by screening the titles and abstracts, then reviewed the full text of eligible articles for the final decision, and assessed the reference list of included articles to determine any missed articles. Two authors (Q.M. and J.Z.) examined the articles independently, and any discrepancies in the selection process were discussed with the third author (H.W.).

Data Analysis

We extracted study characteristics, intervention strategies, and post-intervention data of outcomes from the included articles for our meta-analysis. We first considered all articles with sensor-based interventions and traditional physical therapies to perform a meta-analysis to obtain a global comparative result. Then, we divided the sensor technologies into three categories, including optical sensors (e.g., visually tracking full-body movement), perception sensors (e.g., measuring the pressure center of the feet), and wearable sensors (e.g., tracking part-body motion). A subgroup meta-analysis was performed for each of the three sensor categories.

We employed the mean differences in balance outcomes and 95% confidence interval (CI) to examine the effect size of each trial. The inconsistency test (I^2) was used to evaluate the heterogeneity of the studies. If the I^2 value was less than 40%, a fixed-effect model was utilized to pool the effect size; otherwise, we used a random-effect model (Deeks et al., 2019). The publication bias was assessed through Egger's regression tests (Egger et al., 1997). All meta-analyses were conducted by Comprehensive Meta-Analysis 3.0 (Biostat, Inc., Tampa, FL, USA). All significance levels were predetermined at $p < 0.05$.

Two authors (Q.M. and J.Z.) independently assessed the bias risks of the included articles using the revised Cochrane Risk-of-Bias tool (Higgins et al., 2016). Based on the Grading of Recommendations Assessment, Development, and Evaluation system (Guyatt et al., 2008), we identified the quality of evidence as high, moderate, low, or very low.

Results

A total of 6,154 articles were initially obtained from the six selected databases. After removing 2,154 duplicates, we screened the titles and abstracts of 4,000 potential articles, 211 of which were included based on the inclusion criteria. We included 21 articles after reviewing the full text of the 211 relevant articles. Four more articles were added from the reference list of the included 21 articles. Thus, 25 articles were finally considered and included in this study and subsequent analysis (see Figure 1).

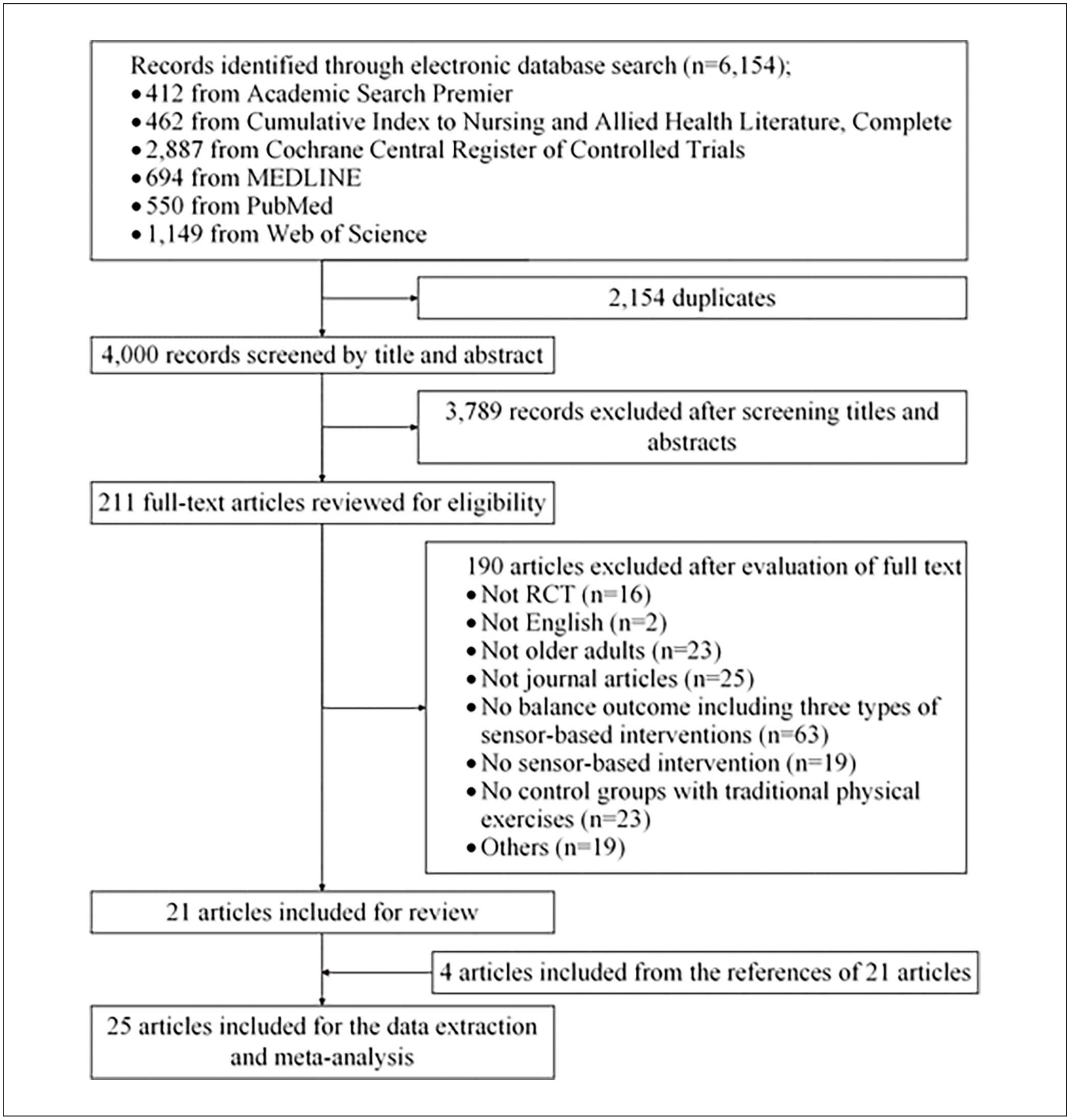


Figure 1. The flow of the literature search and selection process.

A total of 1,625 participants were tested in the included studies, with 750 participants in sensor-based intervention groups and 875 in traditional physical therapy groups. The mean age of participants ranged from 61.1 years to 81.5 years in sensor-based intervention groups and from 61.9 years to 81.6 years in traditional physical therapy groups. Among the included 25 studies, 11 studies tested optical sensors (Chen et al., 2020; Chow & Mann, 2015; Hagedorn & Holm, 2010; Htut et al., 2018; Ku et al., 2019; Lee, 2020; Moreira et al., 2021; Park et al., 2017; Sadeghi et al., 2021; Shih et al., 2016; Yeşilyaprak et al., 2016), 11 studies examined perception sensors (Alagumoorthi et al., 2022; Cho et al., 2012; Choi et al., 2017; Hou & Li, 2022; Khushnood et al., 2021; Kwok & Pua, 2016; Liao et al., 2015; Padala et al., 2012; Park et al., 2015; Pluchino et al., 2012; Singh et al., 2012), and 3 studies used wearable sensors (Bao et al., 2018; Bao et al., 2022; Yoon & Son, 2020). It was worth noting that there were two trials in each of two included studies (Choi et al., 2017; Pluchino et al., 2012). The periods (mean $\pm$ SD) of the sensor-based interventions examined in the 25 included studies were: 45.80 $\pm$ 16.18 minutes per session, 3.32 $\pm$ 1.52 sessions per week, and 7.44 $\pm$ 2.97 weeks.

As shown in Figure 2-a, a significant difference existed between the sensor-based intervention groups and the traditional physical therapies groups ($I^2 < 0.001\%$, mean difference (MD) = -0.448s, 95% CI = -0.641 to -0.255, $p < 0.001$). Our subgroup analysis showed a significant difference between the sensor-based intervention groups with optical sensors and the traditional physical therapies groups ($I^2 = 5.700\%$, MD = -0.681 s, 95% CI = -0.964 to -0.399, $p < 0.001$) (See Figure 2-b). However, no significant difference existed between the traditional physical therapy groups and the sensor-based intervention groups with wearable sensors ($I^2 < 0.001\%$, MD = -0.490 s, 95% CI = -1.474 to 0.493, $p = 0.328$) (See Figure 2-c) or perception sensors ($I^2 < 0.001\%$, MD = -0.226 s, 95% CI = -0.499 to 0.048, $p = 0.106$) (See Figure 2-d).

Only one of the 25 included studies had a high risk of bias (Hagedorn & Holm, 2010). The evidence quality for the effects on TUG test scores was assessed as high for perception sensors vs. traditional physical therapies, moderate for optical sensors vs. traditional physical therapies, moderate for wearable sensors vs. traditional physical therapies, and moderate for all sensors vs. traditional physical therapies. The result of Egger's regression tests showed no publication bias in the included articles ($p = 0.003$).

Discussion

Sensor-based interventions performed better than traditional physical therapies in improving older adults' TUG balance performance. Interestingly, optical sensors showed significant improvement compared to traditional physical therapies in the sub-analyses, consistent with previous studies (Liu et al., 2022); whereas perception and wearable sensors revealed no effectiveness difference with traditional physical therapies. One possible reason for the conflicting results is that the optical sensors allow the users to move in a large space and try different training activities; while the perception sensor generally has a fixed space for movement and thus limits the user's activity. Besides, in the 25 included articles, optical sensors provided whole body's motion feedback while most wearable sensors captured upper-body's motion. The movement signals from the lower trunk are more useful and informative than signals from the upper trunk in improving balance (Halická et al., 2014). Therefore, interventions using optical sensors performed better than the other two sensors. Furthermore, interventions using optical sensors have some limitations. First, optical sensors were suggested for users without neurological impairment due to the complex operation and setting. Perception sensors, such as the Wii balance board, have proven to be better than some optical sensors (Kinect) in enhancing functional improvements among people with Parkinson's diseases (Marotta et al., 2022). Second, the optical sensors may raise privacy issues compared to other two types of sensors. Therefore, we recommend more research to explore the optimal sensor technology for balance training in older adults with specific diseases.

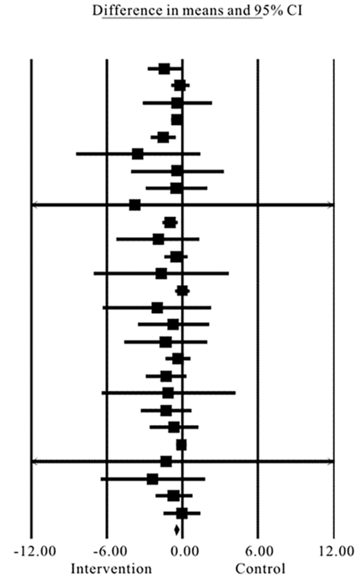
The practitioners should be cautious when applying our findings due to some limitations. First, we included a general population of older adults without specifying their health status. The effectiveness of sensor-based interventions and traditional physical therapies may or may not differ after subgrouping participants' diseases (e.g., hypertension, diabetes, and stroke). Second, this study only used the TUG test result to assess balance performance due to the limited trials. More RCTs with multiple outcomes should be conducted to fully compare the effectiveness of sensor-based interventions and traditional physical therapies in balance improvement.

Conclusion

The present meta-analyse study showed that sensor-based interventions, particularly optical sensors, performed better than traditional physical therapies in balance improvement among older adults. However, no significant differences were found between traditional physical therapies and perception or wearable sensors. Practitioners and future studies are strongly suggested to explore optical sensors' potential impact and application for balance training and rehabilitation among older adults.

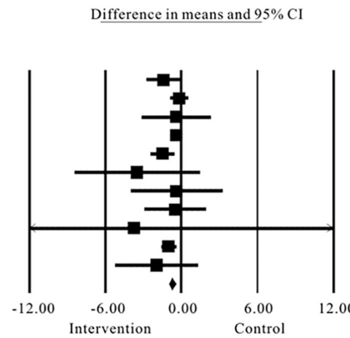
(a)

Study name	Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Sadeghi, et al, 2021	-1.400	0.677	0.459	-2.727	-0.073	-2.067	0.039
Moreira, et al, 2021	-0.160	0.362	0.131	-0.869	0.549	-0.442	0.658
Lee, 2021	-0.410	1.376	1.893	-3.106	2.286	-0.298	0.766
Ku, et al, 2019	-0.418	0.222	0.049	-0.853	0.017	-1.884	0.060
Chen, et al, 2020	-1.500	0.491	0.241	-2.462	-0.538	-3.057	0.002
Hagedorn, et al, 2010	-3.500	2.506	6.280	-8.412	1.412	-1.397	0.163
Yesilyaprak, et al, 2016	-0.400	1.845	3.403	-4.015	3.215	-0.217	0.828
Shih, et al, 2016	-0.470	1.222	1.494	-2.865	1.925	-0.385	0.701
Park, et al, 2017	-3.770	12.319	151.749	-27.914	20.374	-0.306	0.760
Htut, et al, 2018	-1.000	0.290	0.084	-1.568	-0.432	-3.452	0.001
Chow, et al, 2015	-1.940	1.658	2.749	-5.190	1.310	-1.170	0.242
Khushnood, et al, 2021	-0.510	0.449	0.202	-1.391	0.371	-1.135	0.256
Park, et al, 2015	-1.700	2.714	7.367	-7.020	3.620	-0.626	0.531
Kwok, et al, 2016	0.000	0.269	0.073	-0.528	0.528	0.000	1.000
Choi, et al, 2017-1	-2.020	2.182	4.761	-6.297	2.257	-0.926	0.355
Choi, et al, 2017-2	-0.710	1.437	2.066	-3.527	2.107	-0.494	0.621
Cho, et al, 2012	-1.320	1.668	2.782	-4.589	1.949	-0.791	0.429
Singh, et al, 2013	-0.370	0.493	0.243	-1.337	0.597	-0.750	0.453
Liao, et al, 2015	-1.300	0.798	0.638	-2.865	0.265	-1.628	0.103
Padala, et al, 2012	-1.100	2.695	7.265	-6.383	4.183	-0.408	0.683
Pluchino, et al, 2012-1	-1.260	1.011	1.022	-3.241	0.721	-1.247	0.213
Pluchino, et al, 2012-2	-0.680	0.961	0.923	-2.563	1.203	-0.708	0.479
Hou, et al, 2022	-0.080	0.206	0.043	-0.485	0.325	-0.388	0.698
Alagumoorthi, et al, 2022	-1.290	7.642	58.405	-16.269	13.689	-0.169	0.866
Yoon, et al, 2020	-2.370	2.100	4.408	-6.485	1.745	-1.129	0.259
Bao, et al, 2018	-0.700	0.727	0.528	-2.125	0.725	-0.963	0.336
Bao, et al, 2022	-0.046	0.735	0.540	-1.486	1.394	-0.063	0.950
	-0.448	0.098	0.010	-0.641	-0.255	-4.559	0.000



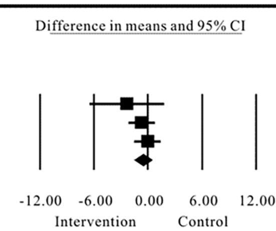
(b)

Study name	Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Sadeghi, et al, 2021	-1.400	0.677	0.459	-2.727	-0.073	-2.067	0.039
Moreira, et al, 2021	-0.160	0.362	0.131	-0.869	0.549	-0.442	0.658
Lee, 2021	-0.410	1.376	1.893	-3.106	2.286	-0.298	0.766
Ku, et al, 2019	-0.418	0.222	0.049	-0.853	0.017	-1.884	0.060
Chen, et al, 2020	-1.500	0.491	0.241	-2.462	-0.538	-3.057	0.002
Hagedorn, et al, 2010	-3.500	2.506	6.280	-8.412	1.412	-1.397	0.163
Yesilyaprak, et al, 2016	-0.400	1.845	3.403	-4.015	3.215	-0.217	0.828
Shih, et al, 2016	-0.470	1.222	1.494	-2.865	1.925	-0.385	0.701
Park, et al, 2017	-3.770	12.319	151.749	-27.914	20.374	-0.306	0.760
Htut, et al, 2018	-1.000	0.290	0.084	-1.568	-0.432	-3.452	0.001
Chow, et al, 2015	-1.940	1.658	2.749	-5.190	1.310	-1.170	0.242
	-0.681	0.144	0.021	-0.964	-0.399	-4.731	0.000



(c)

Study name	Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Yoon, et al, 2020	-2.370	2.100	4.408	-6.485	1.745	-1.129	0.259
Bao, et al, 2018	-0.700	0.727	0.528	-2.125	0.725	-0.963	0.336
Bao, et al, 2022	-0.046	0.735	0.540	-1.486	1.394	-0.063	0.950
	-0.490	0.502	0.252	-1.474	0.493	-0.977	0.328



(d)

Study name	Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Khushnood, et al, 2021	-0.510	0.449	0.202	-1.391	0.371	-1.135	0.256
Park, et al, 2015	-1.700	2.714	7.367	-7.020	3.620	-0.626	0.531
Kwok, et al, 2016	0.000	0.269	0.073	-0.528	0.528	0.000	1.000
Choi, et al, 2017-1	-2.020	2.182	4.761	-6.297	2.257	-0.926	0.355
Choi, et al, 2017-2	-0.710	1.437	2.066	-3.527	2.107	-0.494	0.621
Cho, et al, 2012	-1.320	1.668	2.782	-4.589	1.949	-0.791	0.429
Singh, et al, 2013	-0.370	0.493	0.243	-1.337	0.597	-0.750	0.453
Liao, et al, 2015	-1.300	0.798	0.638	-2.865	0.265	-1.628	0.103
Padala, et al, 2012	-1.100	2.695	7.265	-6.383	4.183	-0.408	0.683
Pluchino, et al, 2012-1	-1.260	1.011	1.022	-3.241	0.721	-1.247	0.213
Pluchino, et al, 2012-2	-0.680	0.961	0.923	-2.563	1.203	-0.708	0.479
Hou, et al, 2022	-0.080	0.206	0.043	-0.485	0.325	-0.388	0.698
Alagumoorthi, et al, 2022	-1.290	7.642	58.405	-16.269	13.689	-0.169	0.866
	-0.226	0.140	0.019	-0.499	0.048	-1.617	0.106

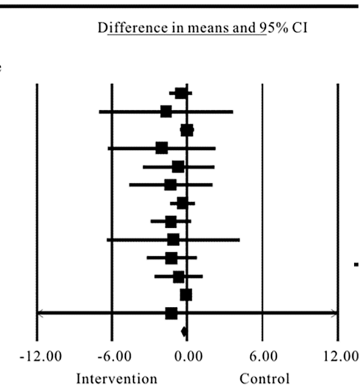


Figure 2. Forest plots for the effects of sensor-based intervention groups, i.e., (a) all sensor technologies, (b) optical sensors, (c) wearable sensors, and (d) perception sensors, on TUG as compared with traditional physical therapy groups.

Acknowledgments

This work was supported by the Shenzhen-Hong Kong-Macao Science and Technology Project Fund [no. SGDX20210823103403028], Health and Medical Research Fund [20211201], and Joint Postdoc Scheme with Non-local Institutions at Hong Kong Polytechnic University [P0042959].

ORCID iDs

Fan YANG https://orcid.org/0000-0002-2482-7884

Hailiang WANG https://orcid.org/0000-0002-6668-7947

Reference

Akin, H., Senel, A., Taskiran, H., & Kaya Mutlu, E. (2021). Do motor-cognitive and motor–motor dual task training effect differently balance performance in older adults? *European geriatric medicine*, *12*, 371-378.

Alagumoorthi, G., & Thirunavukarasu, S. V, R. (2022). Effectiveness of Wii sports-based strategy training in reducing risk of falling, falls and improving quality of life in adults with idiopathic Parkinson's disease-a randomized comparative trial. *Clinical rehabilitation*, *36*(8), 1097-1109.

Bao, T., Carender, W. J., Kinnaird, C., Barone, V. J., Peethambaran, G., Whitney, S. L., Kabeto, M., Seidler, R. D., & Sienko, K. H. (2018). Effects of long-term balance training with vibrotactile sensory augmentation among community-dwelling healthy older adults: a randomized preliminary study. *Journal of neuroengineering and rehabilitation*, *15*(1), 1-13.

Bao, T., Noohi, F., Kinnaird, C., Carender, W. J., Barone, V. J., Peethambaran, G., Whitney, S. L., Seidler, R. D., & Sienko, K. H. (2022). Retention effects of long-term balance training with vibrotactile sensory augmentation in healthy older adults. *Sensors*, *22*(8), 3014.

Barker, A. L., Bird, M.-L., & Talevski, J. (2015). Effect of pilates exercise for improving balance in older adults: a systematic review with meta-analysis. *Archives of physical medicine and rehabilitation*, *96*(4), 715-723.

Chen, M., Wang, H., Yu, L., Yeung, E. H. K., Luo, J., Tsui, K.-L., & Zhao, Y. (2022). A Systematic Review of Wearable Sensor-Based Technologies for Fall Risk Assessment in Older Adults. *Sensors*, *22*(18), 6752.

Chen, P.-J., Penn, I.-W., Wei, S.-H., Chuang, L.-R., & Sung, W.-H. (2020). Augmented reality-assisted training with selected Tai-Chi movements improves balance control and increases lower limb muscle strength in older adults: A prospective randomized trial. *Journal of Exercise Science & Fitness*, *18*(3), 142-147.

Cho, K. H., Lee, K. J., & Song, C. H. (2012). Virtual-reality balance training with a video-game system improves dynamic balance in chronic stroke patients. *The Tohoku journal of experimental medicine*, *228*(1), 69-74.

Choi, H.-S., Shin, W.-S., Bang, D.-H., & Choi, S.-J. (2017). Effects of game-based constraint-induced movement therapy on balance in patients with stroke: a single-blind randomized controlled trial. *American journal of physical medicine & rehabilitation*, *96*(3), 184-190.

Chow, D. H., & Mann, S. K. (2015). Effect of cyber-golfing on balance amongst the elderly in Hong Kong: a pilot randomised trial. *Hong Kong Journal of Occupational Therapy*, *26*(1), 9-13.

Deeks, J. J., Higgins, J. P., Altman, D. G., & Group, C. S. M. (2019). Analysing data and undertaking meta-analyses. *Cochrane handbook for systematic reviews of interventions*, 241-284.

Egger, M., Smith, G. D., Schneider, M., & Minder, C. (1997). Bias in meta-analysis detected by a simple, graphical test. *Bmj*, *315*(7109), 629-634.

Guyatt, G. H., Oxman, A. D., Vist, G. E., Kunz, R., Falck-Ytter, Y., Alonso-Coello, P., & Schünemann, H. J. (2008). GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. *Bmj*, *336*(7650), 924-926.

Haddad, Y. K., Bergen, G., & Florence, C. (2019). Estimating the economic burden related to older adult falls by state. *Journal of public health management and practice: JPHMP*, *25*(2), E17.

Hagedorn, D., & Holm, E. (2010). Effects of traditional physical training and visual computer feedback training in frail elderly patients. A randomized intervention study. *European journal of physical and rehabilitation medicine*, *46*(2), 159-168.

Halická, Z., Lobotková, J., Bučková, K., & Hlavačka, F. (2014). Effectiveness of different visual biofeedback signals for human balance improvement. *Gait & posture*, *39*(1), 410-414.

Higgins, J. P., Sterne, J. A., Savovic, J., Page, M. J., Hróbjartsson, A., Boutron, I., Reeves, B., & Eldridge, S. (2016). A revised tool for assessing risk of bias in randomized trials. *Cochrane database of systematic reviews*, *10*(Suppl 1), 29-31.

Higgins, J. P., Thomas, J., Chandler, J., Cumpston, M., Li, T., Page, M. J., & Welch, V. A. (2019). *Cochrane handbook for systematic reviews of interventions*. John Wiley & Sons.

Hou, H.-Y., & Li, H.-J. (2022). Effects of exergame and video game training on cognitive and physical function in older adults: A randomized controlled trial. *Applied Ergonomics*, *101*, 103690.

Htut, T. Z. C., Hiengkaew, V., Jalayondeja, C., & Vongsirinavarat, M. (2018). Effects of physical, virtual reality-based, and brain exercise on physical, cognition, and preference in older persons: a randomized controlled trial. *European review of aging and physical activity*, *15*(1), 1-12.

Khushnood, K., Altaf, S., Sultan, N., Awan, M. A., Mehmood, R., & Qureshi, S. (2021). Role Wii Fit exer-games in improving balance confidence and quality of life in elderly population. *J. Pak. Med. Assoc*, *71*, 2130-2134.

Ku, J., Kim, Y. J., Cho, S., Lim, T., Lee, H. S., & Kang, Y. J. (2019). Three-dimensional augmented reality system for balance and mobility rehabilitation in the elderly: a randomized controlled trial. *Cyberpsychology, Behavior, and Social Networking*, *22*(2), 132-141.

Kwok, B. C., & Pua, Y. H. (2016). Effects of WiiActive exercises on fear of falling and functional outcomes in community-dwelling older adults: a randomised control trial. *Age and ageing*, *45*(5), 621-627.

Lee, K. (2020). Virtual reality gait training to promote balance and gait among older people: a randomized clinical trial. *Geriatrics*, *6*(1), 1.

Liao, Y.-Y., Yang, Y.-R., Cheng, S.-J., Wu, Y.-R., Fuh, J.-L., & Wang, R.-Y. (2015). Virtual reality–based training to improve obstacle-crossing performance and dynamic balance in patients with Parkinson's disease. *Neurorehabilitation and neural repair*, *29*(7), 658-667.

Liu, C.-L., Cheng, F.-Y., Wei, M.-J., & Liao, Y.-Y. (2022). Effects of exergaming-based tai chi on cognitive function and dual-task gait performance in older adults with mild cognitive impairment: a randomized control trial. *Frontiers in aging neuroscience*, *14*.

Marotta, N., Demeco, A., Indino, A., de Scorpio, G., Moggio, L., & Ammendolia, A. (2022). Nintendo Wiitm versus Xbox Kinecttm for functional locomotion in people with Parkinson's disease: a systematic review and network meta-analysis. *Disability and rehabilitation*, *44*(3), 331-336.

Merchant, R., Morley, J., & Izquierdo, M. (2021). Exercise, aging and frailty: guidelines for increasing function. In (Vol. 25, pp. 405-409): Springer.

Moreira, N. B., Rodacki, A. L., Costa, S. N., Pitta, A., & Bento, P. C. (2021). Perceptive–cognitive and physical function in pre-frail older adults: Exergaming versus traditional multicomponent training. *Rejuvenation Research*, *24*(1), 28-36.

Padala, K. P., Padala, P. R., Malloy, T. R., Geske, J. A., Dubbert, P. M., Dennis, R. A., Garner, K. K., Bopp, M. M., Burke, W. J., & Sullivan, D. H. (2012). Wii-fit for improving gait and balance in an assisted living facility: a pilot study. *Journal of aging research, 2012*.

Park, D.-S., Lee, D.-G., Lee, K., & Lee, G. (2017). Effects of virtual reality training using Xbox Kinect on motor function in stroke survivors: a preliminary study. *Journal of Stroke and Cerebrovascular Diseases*, *26*(10), 2313-2319.

Park, E.-C., Kim, S.-G., & Lee, C.-W. (2015). The effects of virtual reality game exercise on balance and gait of the elderly. *Journal of physical therapy science*, *27*(4), 1157-1159.

Pluchino, A., Lee, S. Y., Asfour, S., Roos, B. A., & Signorile, J. F. (2012). Pilot study comparing changes in postural control after training using a video game balance board program and 2 standard activity-based balance intervention programs. *Archives of physical medicine and rehabilitation*, *93*(7), 1138-1146.

Sadeghi, H., Jehu, D. A., Daneshjoo, A., Shakoor, E., Razeghi, M., Amani, A., Hakim, M. N., & Yusof, A. (2021). Effects of 8 weeks of balance training, virtual reality training, and combined exercise on lower limb muscle strength, balance, and functional mobility among older men: a randomized controlled trial. *Sports Health*, *13*(6), 606-612.

Shih, M.-C., Wang, R.-Y., Cheng, S.-J., & Yang, Y.-R. (2016). Effects of a balance-based exergaming intervention using the Kinect sensor on posture stability in individuals with Parkinson's disease: a single-blinded randomized controlled trial. *Journal of neuroengineering and rehabilitation*, *13*(1), 1-9.

Singh, D. K. A., Rajaratnam, B., Palaniswamy, V., Raman, V., Bong, P., & Pearson, H. (2012). Effects of balance-focused interactive games compared to therapeutic balance classes for older women. *Climacteric*, *16*(1), 141-146.

Soh, S. L.-H., Tan, C.-W., Thomas, J. I., Tan, G., Xu, T., Ng, Y. L., & Lane, J. (2021). Falls efficacy: Extending the understanding of self-efficacy in older adults towards managing falls. *Journal of frailty, sarcopenia and falls*, *6*(3), 131.

Truijen, S., Abdullahi, A., Bijsterbosch, D., van Zoest, E., Conijn, M., Wang, Y., Struyf, N., & Saeys, W. (2022). Effect of home-based virtual reality training and telerehabilitation on balance in individuals with Parkinson disease, multiple sclerosis, and stroke: a systematic review and meta-analysis. *Neurological Sciences*, *43*(5), 2995-3006.

Unbehaun, D., Aal, K., Vaziri, D. D., Wieching, R., Tolmie, P., & Wulf, V. (2018). Facilitating collaboration and social experiences with videogames in dementia: Results and implications from a participatory design study. *Proceedings of the ACM on Human-Computer Interaction*, *2*(CSCW), 1-23.

Yeşilyaprak, S. S., Yıldırım, M. Ş., Tomruk, M., Ertekin, Ö., & Algun, Z. C. (2016). Comparison of the effects of virtual reality-based balance exercises and conventional exercises on balance and fall risk in older adults living in nursing homes in Turkey. *Physiotherapy theory and practice*, *32*(3), 191-201.

Yoon, S., & Son, H. (2020). Effects of full immersion virtual reality training on balance and knee function in total knee replacement patients: a randomized controlled study. *Journal of Mechanics in Medicine and Biology*, *20*(09), 2040007.

Zhang, J., Luximon, Y., Pang, M. Y., & Wang, H. (2022). Effectiveness of exergaming-based interventions for mobility and balance performance in older adults with Parkinson's disease: systematic review and meta-analysis of randomised controlled trials. *Age and ageing*, *51*(8), afac175.