Exploring the Effects of Footwear against Fall Incidents Amongst Older Adults: A Review for Design Enhancement

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Abstract

Slip, trip, and fall (STF) incidents annually affect millions of people of all ages and genders, but older adults are more susceptible. In the elder population, general physical decline, age-related illnesses, mobility issues, and foot deformities play a major role and further aggravate the risk and severity of STFs. Although abundant factors have been found in the literature, shoes seem to be a major contributor to STF incidents. Shoes should not only support the basic functions of retaining stability and preventing foot aches but shield the foot and provide the necessary traction features needed to guard against possible STFs. However, the safety issues of shoes for elderly fall prevention have not been systematically explored. Thus, this study meticulously reviews the current research and practices on the effects of footwear on elderly fall prevention. The literature review was based on five main search keywords: footwear properties, older adults, slips, trips, and falls through the databases of Google Scholar, ScienceDirect, SCOPUS, MEDLINE, ResearchGate, and PubMed to find answers for the main questions on footwear effects against the elderly falls. The review was also focused on footwear design features: fit, fixation, heel height, collar height, slip resistance, and sole/insole hardness. It is expected that findings from this review study may contribute to the present literature by offering suggestions for optimal footwear choices to promote comfort, stability, and safety against STF incidents in older adults' daily lives.

Keywords
Footwear properties, Older adults, Slips, Trips, Falls

1. Introduction
Populations around the world are aging rapidly due to a continuous rise in average life expectancy. It is predicted that persons aged 65 years and older will make up 12% of the global populace by 2030 and 16.7% by 2050 (He et al. 2016). Concurrently, the labor force across various industries is aging, with this trend projected to continue over the upcoming years (Truxillo et al. 2015). Owing to such demographic and societal changes, the burden of injuries and costs associated with elderly STF incidents has become more evident.

Approximately 37.3 million fall incidents that require medical care are reported annually (World Health Organization 2022). By the World Health Organization (2022), fall incidents are the second most prominent cause of unintentional injury deaths following road traffic injuries. Although different age groups are prone to experiencing STFs, older people are more susceptible, and tend to face the highest risk of serious injuries and fatalities (World Health Organization 2022). More than 30% of adults above the age of 65 suffer a fall each year, with a recurrence in 50% of those cases (Tinetti et al. 1988). As the rate of fall injury hospitalizations increases (Watson and Mitchell 2011), it becomes more economically taxing for patients, caregivers, and healthcare systems (Alekna et al. 2015), (Heinrich et al. 2010). STFs can also lead to detrimental psychological effects, whereby 60% of older adults with a fall history report a fear of falls, which in turn can have an adverse effect on their functionality and lifestyle (Hill et al. 2010).

2. Background Information
2.1 Physical Factors
Frailty in those over 65 is high (between 6.9% and 8.4%) and continues to increase with age (Fried et al. 2001), (Garcia-Garcia et al. 2011). Older adults are more likely to suffer from musculoskeletal disorders that decrease their functionality and mobility (Cuevas-Trisan 2019). Their feet are prone to exhibit lower sensitivity (Machado et al.

2016), weakness, decreased range of motion, increased soft tissue stiffness, and postural pronation (Menz 2015). Older adults also commonly display improper gait patterns caused by a variety of medical conditions (Cuevas-Trisan 2019). These factors coupled with their longer response time to abrupt situations (Dionyssiotis 2012) can impair their balance control and lead to STFs. Chronic illnesses and persistent pain have also been closely linked to falls (Gale et al. 2016), with the common co-existence of multiple illnesses, resulting in a high number of used medications (Crentsil et al. 2010), which can further aggravate the side effects experienced and increase the risk of STFs (Crentsil et al. 2010), (Cuevas-Trisan 2019).

2.2 Footwear

Majority of the literature available on STF incidents affecting older adults primarily focuses on intrinsic risk factors such as activity levels, functional and cognitive disabilities, ambulatory status, chronic diseases, use of walking aids, medication use, as well as several socio-demographic and socio-economic aspects such as gender, marriage status, employment status, living conditions, and education (Cuevas-Trisan 2019), (Dionyssiotis 2012), (Gale et al. 2016). Moreover, in evaluations of extrinsic risk factors, footwear features are often underestimated or overlooked as they are thought to have less impact on safe ambulation and STF prevention compared to factors such as floor surface textures and designs, pathway obstacles, and environmental conditions. However, footwear interventions have proven to have substantial influences on both static and dynamic stability and gait in older adults (Hatton et al. 2013) and may be an easier, faster, and more cost-efficient element to modify. Therefore, identifying and examining specific footwear characteristics that may promote or compromise balance in older adults is essential to providing a solid foundation for promoting fall safety and reducing footwear-related fall incidents.

2.3 Objective

The objective of this study is to investigate the recent literature concerning older adults' footwear issues specifically footwear fit, fixation, heel height, collar height, slip resistance and sole/insole hardness. Thus, the following main research questions are posed:

- What is the prevalence of the selected features in older adults' footwear?
- How do the selected features affect older adults' comfort, balance, gait, and/or slip resistance?
- What is the effect of the selected footwear features on possible STF incidents?
- What are the optimal footwear features to safeguard older adults against STFs?

3. Methods

To find answers to the main research questions, this review study was explored with five primary search keywords: footwear properties, older adults, slips, trips, and falls through the databases of Google Scholar, ScienceDirect, SCOPUS, MEDLINE, ResearchGate, and PubMed. The inclusion criteria were:

(a) Studies published in the English language.
(b) Studies published from the year 2012 onwards.
(c) Study subjects included adults aged 60 years and older.
(d) Study outcomes identifying the prevalence of selected footwear properties and/or footwear-related effects on comfort, balance, gait, slip resistance, and associated risks of STF incidents.

Prioritizing studies published since 2012 was mainly to identify the latest information and practices on the topic, building on previous knowledge. Only 4 studies examining sole tread effects (Beschorner and Singh 2012), (Beschorner et al. 2014), (Sundaram et al. 2020), (Ziaei et al. 2013) that did not involve older adults were included due to the shortage of studies that met the inclusion criteria.

Fig.1 summarizes the articles' screening and selection process.

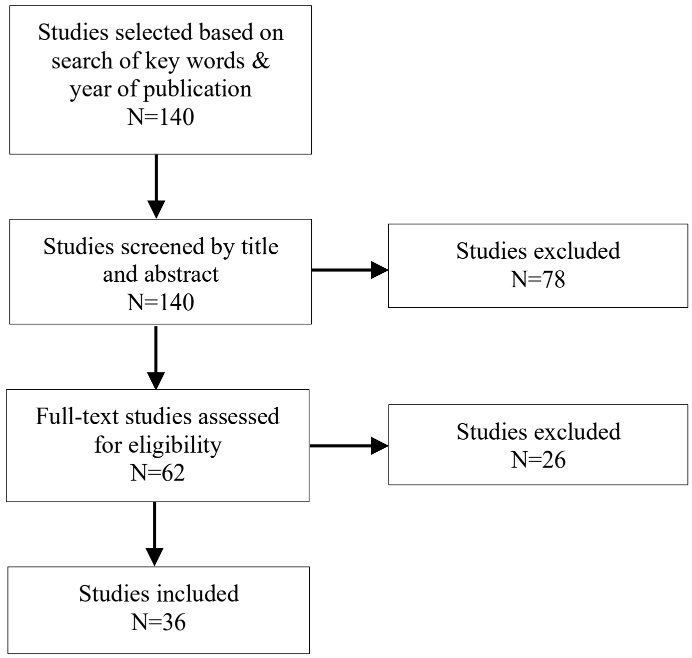

Figure 1. Flowchart of article screening and selection

4. Results and Discussion

4.1 Fit (FT)

Fit is an important footwear feature to consider because it regulates comfort and functionality (Jellema et al. 2019). Although some older adults choose correctly fitted footwear (Vass et al. 2015), the opposite seems to be more prevalent. In a descriptive observational study of 100 elderly subjects at an outpatient clinic, López et al. (2015) found that 83% wore ill-fitting footwear on at least one foot, while in a case-control study of fall risk factors in 333 elderly people, Kuhirunyaratn et al. (2013) found that 34% of men and 50% of women wore excessively narrow footwear that resulted in aches. This proclivity to choose ill-fitted footwear may be ascribed to older adults suffering from lower feet sensitivity, not getting their feet routinely checked (López et al. 2015), not being conscious of their right footwear size, or being incapable of choosing footwear that is correctly adapted to variations in their feet morphology (Buldt and Menz 2018).

O'Rourke et al.'s (2020) assessment revealed similar findings, recognizing that 72% of older adults wore ill-fitting shoes, with the percentage of those who fell in the previous 6 months being higher among those wearing ill-fitting footwear at 56%, compared to 39% among those who wore shoes that fit at least 1 foot. However, this finding was not statistically significant. Additionally, in a recent comparative study of 153 elderly subjects, 60% were found to be wearing ill-fitting footwear, and out of whom, 26% had suffered a fall during the past year compared to just 15% of those wearing properly fitted footwear. Those wearing ill-fitted shoes also scored lower on the Berg Balance Scale (BBS) and had a greater dread of falling based on the Activities-specific Balance Confidence Scale (ABC) (Maden et al. 2021).

Well-fitted footwear can thus improve older adults' stability, gait, and social activity as well as reduce their fear of falling (Jellema et al. 2019), (Maden et al. 2021) and would be a suitable recommendation to reduce the risk of STFs.

4.2 Fixation (FX)

Heel slippage associated with lack of appropriate fixation may place higher strains on the lower limb motor control system to hold the footwear in place (Davis et al. 2016). Securing the foot within the footwear is thus vital to maintain its stability and allow for suitable direction over possible trip hazards (Davis et al. 2016).

A study examining 20 older women's gait while barefoot, wearing backless slippers, less-fixated shoes with a nylon mesh upper and lenient heel counter and well-fixated shoes with a dorsal fixation, belt, and stiff heel counter, showed an increase in the knee and ankle joint angle alterations when participants walked with the slippers and less-fixated shoes. This increased variation was attributed to knee and ankle joint movement changes possibly made to grip the footwear in place, signifying an increase in the risk of trips and falls (Hida et al. 2021). Similarly, when analyzing 70,196 fall incidents experienced by older adults, Buchele et al. (2014) found that open slippers were a significant predictor of falls associated with hospital transfers in older women, given that open slippers have the predisposition to impede stepping motion. Additionally, gait assessments performed on 30 older women showed that shoes with lace fixations increased walking speed, step length and minimum foot clearance while also reducing the step width, step duration, and heel slippage when compared to enclosed slippers lacking dorsal fixation (Davis et al. 2016).

In O'Rourke et al.'s (2020) assessment of older adults' common daily footwear 26% were found to lack fixation, while Vass et al. (2015) reported a higher percentage of 60%. This variance may be attributed to the difference in sample size and the types of footwear considered (indoor and outdoor).

Footwear with appropriate fixation should therefore be recommended to enhance older adults' foot clearance, gait, and stability (Davis et al. 2016) and reduce the risk of trips and falls (Davis et al. 2016), (Hida et al. 2021).

4.3 Heel Height (HH)

An increase in heel elevation can alter the trajectory of center of pressure (COP), foot-ground area of contact, and peak plantar pressure during ambulation (Kim et al. 2012). In addition, a heel height greater than 2.5 cm can raise and alter the body's center of mass (COM) causing postural and kinematic modifications that affect stability (Guidozzi 2017). Heel height can thus have a considerable effect on older adults' lower extremity functions and balance (Aboutorabi et al. 2016) and has been recognized as a fall risk factor (Kim et al. 2012), (Li 2021).

In a study conducted to define the impact of heel height on plantar foot pressure in older women, three different heel heights: 1 cm, 3 cm, and 5 cm were compared. The results showed that gait stability was improved when participants wore 1 or 3 cm heels compared to 5 cm heels, and as a result their risk of falling decreased (Kim et al. 2012).

Although it has been suggested that high heels are unlikely to be the most common type of footwear worn by older women when they fall (Davis et al. 2019), this may be attributed to the practice of wearing high heels decreasing among women as they age. When examining the most common outdoor footwear worn by older women, Menz et al. (2017b) found that high heels accounted for only 3.3%, which is in line with the assertion that wearing high heels with a very narrow toe box decreases to less than 10% in women by the age of 40 (Menz et al. 2016).

Recommendations for safe footwear thus suggest a limited heel height (Aboutorabi et al. 2016), (Jellema et al. 2019), (Roman de Mettelinge et al. 2015), with 4 cm suspected to be the maximum safety threshold of balance (Menz 2021).

4.4 Collar Height (CH)

There is a consensus in the literature that shoes with a high collar height and top line improve older adults' balance and should be considered in the design of safe footwear (Aboutorabi et al. 2016), (Guidozzi 2017), (Jellema et al. 2019).

It is believed that a material covering all sides of the ankle provides mechanical stability to the ankle and subtalar joints in the coronal plane, while an elevated collar height improves proprioceptive feedback compared to regular footwear (Aboutorabi et al. 2016). This is consistent with an experiment performed to evaluate the effects of 3 footwear styles on gait parameters linked to falls in older adults. The types of footwear considered were soft material open-heel shoes with no collar or fastening and 2 closed-heel shoes (differing in hardness of material) with a high collar and velcro fastening. The results showed that the closed-heel and high-collar shoes considerably improved speed, stride length, and step time, and were perceived by participants to be more comfortable and stable (Van der Cammen et al. 2016).

4.5 Slip Resistance (SR)

Slips result from the ratio of traction force to the vertical force put onto the ground reaching the coefficient of friction (COF) between the footwear and the ground (Yamaguchi and Masani 2019). Shoes lacking appropriate slip-resistant properties can therefore be a major contributing factor to falls in older adults (Kim 2022), (Kim 2017), (Li 2021).

4.5.1 Sole Tread

Different tread profiles of shoe soles can help improve slip resistance and reduce the fluid pressure during ground contact, thereby attenuating the lubricating effect of the liquid and the resulting reduction in COF (Beschorner and Singh 2012), (Beschorner et al. 2014). Because older adults take wider steps while walking, the required mediolateral COF increases, causing more slips to occur in the lateral direction. Therefore, sole tread patterns should ideally be designed to offer more slip resistance in both mediolateral (ML) and anteroposterior (AP) directions to reduce the risk of sideway slips (Yamaguchi and Masani 2019).

Although slip tests are seldom performed with older adults due to their hazardous nature, experiments with young adult participants suggest that the presence of a treaded sole and an increase in tread depth significantly improves friction at the shoe-floor interface and reduces the risk and/or severity of slip and fall incidents (Beschorner et al. 2014), (Ziaei et al. 2013). Multiple studies have thus recommended a tread pattern in their proposal for a safe footwear design for older adults (Jellema et al. 2019), (Li 2021), (Roman de Mettelinge et al. 2015).

Another factor to consider in the sole profile is the wear development caused by repeated use, given that worn soles are frequently observed in the evaluation of older adults' indoor and outdoor footwear. O'Rourke et al. (2020) reported wear in 90% of older adults' footwear, while Vass et al. (2015) reported that 60% of older adults' footwear had been owned for more than 1 year with 48% identified to have partially to excessively worn soles. Consequently, as the worn area in the shoe sole increases, the peak fluid pressure under the shoe increases, leading to a decrease in the available COF and an aggravated risk of slipping (Sundaram et al. 2020).

4.5.2 Sole Material

Rubber has been widely used in the design of shoe soles given its proven slip-resistant properties. It has also been incorporated into the design of anti-slip/gripper socks for indoor use.

While anti-slip socks may be a comfortable footwear option for older adults (Vass et al. 2015), there are conflicting findings to support their effectiveness in STF prevention. Hatton et al.'s (2013) fast-paced Timed Up and Go (TUG) test showed that the use of anti-slip socks with rubberized soles enhanced the participants' gait performance on a slippery surface with walking speed and step length, as well as their perception of slipperiness when compared to regular cotton socks. However, Hartung and Lalonde (2017) reported inconclusive evidence regarding their efficacy in the case of hospitalized elderly fall prevention and pointed out the concern for infection spread. It was also indicated that anti-slip socks provided by hospitals may not offer the appropriate heel, forefoot, or sole support needed to foster suitable gait and balance in older adults (Vass et al. 2015).

4.5.3 Anti-slip Devices

Slip-resistant footwear devices have been recommended for older adults to reduce the risk of falls in icy environments (Karlsson et al. 2013) This is supported by a study conducted in Sweden to assess the effects of providing those over 65 years with anti-slip devices such as studded footwear or ice cleats ahead of winter. Results revealed a 45% decrease in the number of slip-related falls reported at the emergency department in the first year post-intervention. However, the insignificance of long-term effects was attributed to the possibility of a short device lifespan (Bonander and Holmberg 2019).

Older adults should thus be advised to choose footwear with appropriate slip-resistant material and tread design and should alternate between their use of footwear, or regularly buy new footwear to mitigate the wear and tear effects caused by excessive use.

4.6 Hardness (HD)

4.6.1 Sole Hardness

Rugged soles have been a commonly recommended footwear feature to reduce the risks of STFs (Aboutorabi et al. 2016), (Jellema et al. 2019), with various study outcomes showing improved balance and/or gait when hard soles were incorporated in footwear design (Menz et al. 2017a), (Menz et al. 2017b). However, there is a shortage of recent studies exclusively examining this footwear characteristic further concerning fall prevention in the elderly population. This may be due to the general acceptance of the validity of this recommendation.

Furthermore, when recommending footwear with hard soles, the expected comfort of wearing them also becomes an important factor to consider. In a study performed to evaluate the effects of wearing 3 identical shoes with varying hardness (Shore A25, A40 and A58) on older adults with forefoot pain, the results showed that even though plantar pressure increased with the increase in sole hardness, there was no difference in comfort scores (Lane et al. 2014).

4.6.2 Insole Hardness

Incorporating insoles in footwear design is intended to offer a pad, aiding in uniform pressure distribution, and retaining suitable orientation of the lower extremities (Park et al. 2021). It has been suggested that unlike soft insoles that can adapt to foot position, harder insoles can have a corrective effect, and help maintain a neutral foot position, thereby improving postural stability (Iglesias et al. 2012).

First, a study was conducted by Iglesias et al. (2012) to investigate the impact of insole hardness on the static balance of older subjects with their eyes open and closed. A soft gel insole and a hard Shore A50 insole were tested. Results showed that the hard insole improved postural sway when visual feedback was eliminated compared to the soft gel insole. Additionally, in a study by Qu (2015) who investigated the effects of different insole designs and materials on the static and dynamic balance of older adults, a soft slow rebound foam sponge insole and a hard polyurethane and Ethylene-Vinyl Acetate (EVA) insole were tested. The hard insoles were found to significantly increase the AP Margin of Stability (MOS), indicating that harder insoles may offer greater dynamic balance in the AP direction.

In contrast, a study performed to examine the effects of a soft-textured insole (270 density EVA) and a hard-textured insole (320 density EVA) on postural sway in younger and older adults on both foam and firm surfaces showed that though young participants performed predominantly better with the hard insoles, old participants did not. The discomfort was also reported when standing on the hard insoles for extended periods, and it was proposed that such insoles may not be the most suitable option for older adults suffering from peripheral neuropathy (Qiu et al. 2012).

Therefore, an increase in sole/insole hardness may be an appropriate recommendation to improve stability, but it is vital to identify the optimal materials and degree of hardness needed to maintain the comfort of wear.

4.7 Optimal Footwear Design

In multiple studies, footwear features expected to improve balance, gait, slip resistance, and/or comfort were collectively integrated into the selection/design and testing of safe footwear for older individuals.

First, spatiotemporal gait analysis was performed on 57 older women while performing a single walking assignment, and double motor and cognitive walking assignments. Participants were barefoot, and wore their backless slippers, high-heeled footwear (≥3.5 cm) and the provided standard footwear. The standard footwear was a walking shoe with lace fixation, marginally round and low heel (< 2.5 cm), EVA foam midsole, solid 6.5 cm heel collar and a treaded sole. Results revealed that the standard shoes significantly increased the participants' gait speed and stride lengths irrespective of the assignment conditions and were the optimally recommended footwear choice (Roman de Mettelinge et al. 2015).

Additionally, a study was conducted by Menz et al. (2017a) to compare the effects of wearing regular socks, backless slippers, and enclosed slippers on older women's gait and balance. The backless slippers had no fixation, with a soft foam (Shore A15) sole of 25 mm uniform thickness while the enclosed slippers had velcro fixation, a hard rubber (Shore A50) sole with 15 mm thickness below the forefoot and 32 mm thickness below the heel, as well as a solid heel counter. The results showed that the enclosed footwear best-supported gait and balance with improved directional control and reduced postural sway, step width, and end sway. Participants also perceived the enclosed slippers to be more comfortable, fitted, and attractive.

Menz et al. (2017b) also conducted separate tests to assess the balance performance and gait of older women while wearing their outdoor footwear, flexible footwear chosen to act as a control, and prototype footwear aimed to optimize performance. The prototype footwear was made of a rubber sole with Shore A55 hardness, 18 mm forefoot sole thickness, and 25 mm heel thickness, including both lace and velcro fixation, a high collar, and a firm heel counter. To enhance slip resistance, a 10-degree bevel was ground into the heel area and a tread of 1.2 mm depth and 2.4 mm width was placed on the heel perpendicular to the sole, while a perpendicular tread of 5 mm depth and 12 mm width was placed on the rest of the sole. A textured EVA insole was also designed with 4 mm thickness, Shore A25 hardness, with dome-shaped ridges of Shore A85 hardness, 3 mm in height and 8 mm in diameter placed under the forefoot in a 15 mm diamond shape and extending laterally on the edge reaching the heel. The results showed that participants performed better with the prototype footwear on the tandem walk test, exhibiting a narrower step width, and lower-end postural sway, which is important to provide older adults' need for lateral stability to reduce the risk of possible STFs.

Similarly, balance tests were conducted on older adults using shoes specifically designed for balance and their outdoor shoes. The balance shoes had a longitudinal track running under the heel and had a space at the midsole to protect the foot from possible balance disturbances caused by pebbles. The midsole had bands 2 mm higher on both sides to improve balance. A metal shank was incorporated into the sole to increase rigidity, while the sole had a circular arc tread to improve slip resistance. The results showed that the balance shoes improved participants' stability on both legs with eyes closed, and the feeling of steadiness and security among most of them (Amiez et al. 2021), (Axis Balance Shoes 2022).

Figure 2. and Table 1. summarize the review results of published studies against the related footwear features' fall risks as mentioned in the results and discussion section.

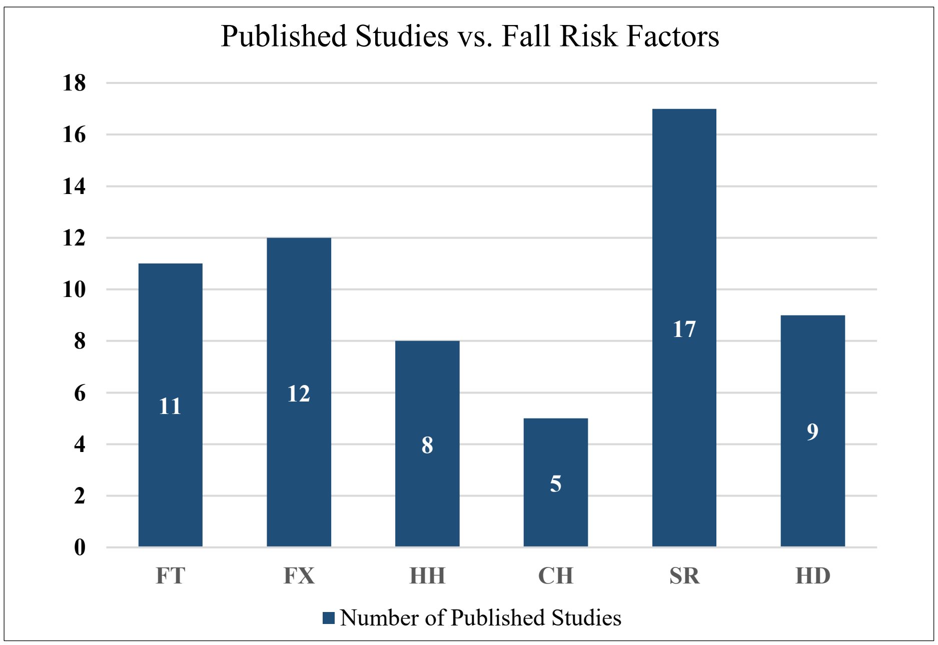

Figure 2. Number of published studies against fall risk factors

Table 1. Summary of published studies vs. fall risk factors

Study (Year)	**Study Design/ Research Methods**	**Fall Risk Factors**					
		FT	**FX**	**HH**	**CH**	**SR**	**HD**
Jellema et al. (2019)	Systematic Review	✓	✓	✓	✓	✓	✓
Vass et al. (2015)	Observational Survey & Interviews	✓	✓	✓		✓	
López et al. (2015)	Descriptive Observational	✓					
Buldt and Menz (2018)	Systematic Review	✓					
Kuhirunyaratn et al. (2013)	Case-control & Interviews	✓				✓	
O'Rourke et al. (2020)	Observational Cross-sectional	✓	✓			✓	
Maden et al. (2021)	Comparative Observational Single Blind	✓					
Davis et al. (2016)	Randomized Control Trial	✓	✓				
Hida et al. (2021)	Experiments		✓				
Büchele et al. (2014)	Prospective Observational		✓				
Kim et al. (2012)	Experiments			✓			
Guidozzi (2017)	Literature Review		✓	✓	✓	✓	
Aboutorabi et al. (2016)	Systematic Review			✓	✓		✓
Menz et al. (2017b)	Experiments & Questionnaire	✓	✓	✓	✓	✓	✓
Li (2021)	Systematic Review & Interviews	✓		✓		✓	
Roman de Mettelinge et al. (2015)	Experiments	✓	✓	✓		✓	✓
Van der Cammen et al. (2016)	Experiments & Questionnaire		✓		✓		
Yamaguchi and Masani (2019)	Data Analysis					✓	
Ziaei et al. (2013)	Semi-experimental					✓	
Beschorner et al. (2014)	Experiments					✓	
Sundaram et al. (2020)	Observational Cross-sectional					✓	
Hatton et al. (2013)	Experiments					✓	
Hartung and Lalonde (2017)	Literature Review					✓	
Karlsson et al. (2013)	Literature Review					✓	
Bonander and Holmberg (2019)	Quasi- Experimental					✓	
Iglesias et al. (2012)	Experiments						✓
Qu (2015)	Experiments						✓
Qiu et al. (2012)	Experiments						✓
Menz et al. (2017a)	Experiments & Questionnaire		✓				✓
Amiez et al. (2021)	Crossover, Controlled, Randomized Single-blind		✓			✓	✓
Total Number of Studies		**11**	**12**	**8**	**5**	**17**	**9**

5. Conclusion

This review study aimed to explore the recent literature on footwear features, and their effects on the prevention of elderly STFs. It has been established that footwear features can have a major impact on static and dynamic balance, gait configurations, and slip proclivity in older adults, and therefore should be a primary consideration in fall-related interventions. Older adults should therefore be advised to get regular foot checks and choose appropriately fitted footwear, with proper fixation, a limited heel height, a high collar height, appropriate slip resistance properties and more rigid soles/insoles. Additionally, when designing footwear for older adults, factors of availability, affordability, aesthetic appeal, comfort, and ease of wear should be considered to increase its acceptability.

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