

## Influence of Footwear on Gait Characteristics that are Associated With Increased Fall Risk in Older Persons

van der Cammen, Tischa; Sterke, CS; Halilovic, A; Molenbroek, Johan

**DOI**

[10.2174/1875934301609010043](https://doi.org/10.2174/1875934301609010043)

**Publication date**

2016

**Document Version**

Final published version

**Published in**

The Ergonomics Open Journal

**Citation (APA)**

van der Cammen, T., Sterke, CS., Halilovic, A., & Molenbroek, J. (2016). Influence of Footwear on Gait Characteristics that are Associated With Increased Fall Risk in Older Persons. *The Ergonomics Open Journal*, 9, 43-49. <https://doi.org/10.2174/1875934301609010043>

**Important note**

To cite this publication, please use the final published version (if applicable). Please check the document version above.

**Copyright**

Other than for strictly personal use, it is not permitted to download, forward or distribute the text or part of it, without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license such as Creative Commons.

**Takedown policy**

Please contact us and provide details if you believe this document breaches copyrights. We will remove access to the work immediately and investigate your claim.



# The Ergonomics Open Journal

Content list available at: [www.benthamopen.com/TOERGJ/](http://www.benthamopen.com/TOERGJ/)

DOI: 10.2174/1875934301609010043



## RESEARCH ARTICLE

# Influence of Footwear on Gait Characteristics that are Associated With Increased Fall Risk in Older Persons

Tischa JM van der Cammen<sup>1,2,3</sup>, Carolyn Shanty Sterke<sup>4,5</sup>, Alen Halilovic<sup>1</sup> and Johan Molenbroek<sup>1,\*</sup>

<sup>1</sup>Faculty of Industrial Design Engineering, Department of Industrial Design, Delft University of Technology, Landbergstraat 15, 2628 CE Delft, The Netherlands

<sup>2</sup>Department of Internal Medicine, Section of Geriatric Medicine, Erasmus University Medical Center, P.O. Box 2040, 3000 CA Rotterdam, The Netherlands

<sup>3</sup>Department of Medicine, Brighton and Sussex Medical School, Brighton, UK

<sup>4</sup>Aafje Nursing Homes, PO BOX 9293, 3007 AG Rotterdam, The Netherlands

<sup>5</sup>Department of Public Health, Erasmus University Medical Center, P.O. Box 2040, 3000 CA Rotterdam, The Netherlands

Received: June 02, 2016

Revised: October 20, 2016

Accepted: October 27, 2016

### Abstract:

#### Objective:

To investigate the influence of three different types of shoe models frequently worn at home, including an open heel shoe model, on gait parameters that are associated with fall risk in older persons.

#### Methods:

Twenty-five community-dwelling independent older persons were asked to walk on an electronic walkway system, the GAITRite<sup>®</sup> walkway, while wearing three different shoe models which are frequently worn at home. We measured spatial and temporal gait parameters.

#### Results:

Gait velocity and stride length were significantly reduced, and step time, stance, and double support time were significantly increased, when older persons wore an open heel shoe model compared to the high collar shoe models.

#### Conclusion:

Wearing an open heel shoe model is associated with gait parameters that are associated with fall risk, compared with a high collar shoe model, in community-dwelling older persons. With regard to falls prevention, further attention for footwear in older persons seems warranted, especially for footwear worn in and around the home.

**Keywords:** Electronic walkway, Footwear, Fall risk, Gait parameters, Older persons.

## 1. INTRODUCTION

Falls are a major problem in the older population. One third of community-dwelling older persons experience a fall at least once a year, of those fallers 50% fall more than once a year [1 - 3]. Most falls occur in and around the home [4], however information on the footwear worn during these falls is not available [4].

\* Address correspondence to this author at the Faculty of Industrial Design Engineering, Department of Industrial Design, Delft University of Technology, Landbergstraat 15, 2628 CE Delft, The Netherlands; Tel: +31152783021; Fax: +31152787179; E-mail: [j.f.m.molenbroek@tudelft.nl](mailto:j.f.m.molenbroek@tudelft.nl)

In a pilot study in the Geriatrics Out Patients Clinic of the Erasmus University Medical Center we found that open heel slippers were the usual and preferred footwear of older people in and around the home [5]. In 2003 the Easington primary care trust found that “sloppy slippers” were responsible for a considerable number of falls [6]. In 2004, a study in residential care homes in New Zealand reported that wearing slippers was associated with injurious falls [7].

Inappropriate footwear has been identified as a contributor of up to 45% of falls [8, 9]. Walking barefoot or in socks can elevate fall risk [10, 11]. Also, wearing shoes with a low collar or a high heel has been shown to increase fall risk and impair balance [12, 13].

Effects of footwear on gait characteristics have been reported [14, 15]. Wearing walking shoes increased gait speed compared to wearing dress shoes [14]. The application of insoles with a mechanical stimulation to the soles of the feet decreased stride-to-stride variability in step width and stride length [15].

In recent years several gait parameters as measured with an electronic walkway system (GAITRite<sup>®</sup>) have been shown to be associated with increased fall risk. Decreased velocity and stride length [16, 17], increased double-support time [18], and increased stride-to-stride variability in swing time [19, 20], have been shown to be associated with risk of falls [16 - 20].

A study with textured insoles worn by older adults with a history of falls did not show any benefit on gait parameters as measured with the electronic walkway system (GAITRite<sup>®</sup>) [21].

Literature on the use of open heel shoe models and fall risk is lacking. We were interested in the possible relationship between use of open heel shoes and fall risk. In this study we used gait parameters as measured with an electronic walkway system as a derivative of fall risk. We investigated the influence of footwear, including an open heel shoe model, on gait parameters which are associated with fall risk in older persons. We consider that this is a preferred and more reliable method for studying footwear in relation to falls, as compared to testing the shoe models in real life situations, where we would have to rely on self-reports of falls and footwear worn during the fall.

## 2. METHODS

### 2.1. Participants

A convenience sample of 25 community-dwelling independent older persons (14 women and 11 men), aged 59-85 years (mean age 68.5 years, SD  $\pm$  6.9), was recruited from visitors of a shoe store specialized in comfort shoes for older people, [www.intersko.com](http://www.intersko.com), between 16 and 27 March 2013. All participants were able to walk independently at least 12 meters and gave their written informed consent. Participants were asked to walk on an electronic walkway system, the GAITRite<sup>®</sup> walkway, while wearing three different shoe models selected because they are frequently worn at home. With every shoe model each participant performed two walks on the walkway, the first walk being a test walk and the second walk the definite walk.

After six walks, the participants were asked whether they had experienced a fall in the past year; three out of 25 were single fallers, *i.e.*, they experienced one fall in the past year; 22 out of 25 were non-fallers. Furthermore, participants were asked to fill in a questionnaire with questions relating to personal preference and experience with the three different shoe models. They had to indicate which shoe model they preferred for five aspects of the shoe, *i.e.*, which shoe is easy to put on, is most comfortable, is most stable, is aesthetically pleasing, would you purchase? For each of the five aspects they could only rate one shoe model as the preferred one.

This study was approved by the Human Research Ethics Committee, Delft University of Technology.

### 2.3. Shoe models

Model 1 was an open heel soft material shoe, without collar. Model 2 was a soft material shoe, with closed heel and a high collar. Model 3 was a hard material shoe, with closed heel and a high collar. Model 2 and model 3 had a closing mechanism with Velcro (see Fig. 1).

#### 2.3.1. Selection Criteria for the Three Shoe Models

Why did we choose for these three shoe models?



**Fig. (1).** Shoe models 1, 2, and 3.

In the current market of shoes there are several solutions to make a shoe fit to the foot shape.

- a. Individual made to measure shoe: *i.e.*, 3D-printing of a shoe after 3D-scanning of a foot shape (Additive Manufacturing).
- b. Adjustable fastening with Velcro or straps or pins
- c. Traditional shoes with laces
- d. Open heel slippers or shoes
- e. Closed heel slippers or shoes.

In putting shoes on and taking them off (donning and doffing), the ease plays an important role. Therefore shoes with laces(c) were excluded from this experiment for indoor shoed feet. Further requirements are the ease of fastening and the ease of adjustments to make the shoe fit.

#### 2.4. Electronic Walkway

We used the GAITRite<sup>®</sup>-732 system (Biometrics France) to measure and record temporal and spatial parameters of gait. The GAITRite<sup>®</sup>-system is a portable computer based electronic roll-up walkway with an overall dimension of 823 cm x 90 cm x 0.6 cm connected to a personal computer with application software for calculation of temporal and spatial parameters of gait. The active area of the walkway is 732 cm x 61 cm. Pressure sensors are embedded into the carpet in a horizontal grid. We followed the guidelines for clinical applications of spatial-temporal gait analysis in older adults [22].

#### 2.5. Gait Parameters

Spatial gait parameters used in this study were: stride length, and heel-to-heel base of support. Temporal parameters used were: cadence (steps/minute), step time, velocity, swing time, stance, and double support time. Variability in the GAITRite<sup>®</sup> parameters step time, swing time, stance, stride length, heel-to-heel base support, and double support time was expressed as coefficients of variation (CV), *i.e.* Standard deviation (SD)/mean \*100%.

#### 2.6. Analysis

The normal distribution of all the gait parameters was tested using the Shapiro–Wilk test. For the parameters that had a normal distribution, a repeated measures analysis of variance (ANOVA) was used to compare gait parameters between the three different shoe models. For the parameters that were not normally distributed, the Friedman test was used. In a post-hoc analysis we compared shoe model 1 to shoe model 2, shoe model 1 to shoe model 3, and shoe model 2 to shoe model 3. Student's paired samples t-test with Bonferroni correction was used for post hoc analysis of the parameters that had a normal distribution. The Wilcoxon signed-rank test was used for the post-hoc analysis of the not-normally distributed gait parameters. A two-sided p value of less than 0.05 was considered as statistically significant.

For each pairwise comparison we calculated Cohen's d and 95% confidence intervals (CIs), which is defined as the difference between two means divided by a standard deviation for the data [23].

All statistical analyses were performed using SPSS software (version 20.0, SPSS INC., Chicago, IL, U.S.A.).

With regard to the personal preference and experience with the three different shoe models, we counted for each shoe model the number of preferences.

### 3. RESULTS

#### 3.1. Gait Parameters

Shoe model 2 and model 3 had a significantly better performance compared to model 1.

We found 5 gait parameters which performed significantly better for shoe model 2 compared to model 1, *i.e.*, velocity, step time, stance, double support time, and stride length.

We found 3 gait parameters which performed significantly better for shoe model 3 compared to model 1, *i.e.*, velocity, step time, and stride length.

Significant gait parameters, the effect sizes, and 95% CIs are shown in Table 1.

**Table 1. Significant differences in GAITRite® parameters between the de different shoe models.**

	Model 1	Model 2				
GaitRite® Parameters	Mean (sd)	Mean (sd)	Difference	p-value	Cohen's d	95% CI
Velocity (cm/s)	102.97 (17.65)	110.13 (18.5)	-7.16	< 0.00	0.39	0.21, 0.57
<i>Stride-to-stride average</i>						
Step time - Left (sec)	0.60 (0.06)	0.57 (0.06)	0.03	< 0.00	-0.36	-0.56, -0.16
Step time - Right (sec)	0.60 (0.08)	0.58 (0.06)	0.02	< 0.00	-0.35	-0.67, -0.05
Stance - Right (sec)	0.76 (0.09)	0.74 (0.08)	0.02	0.02	-0.29	-0.47, -0.10
Double support time - Left (sec)	0.33 (0.06)	0.31 (0.06)	0.02	< 0.00	-0.30	-0.45, -0.16
Stride length - Left (cm)	121.86 (13.11)	125.23 (13.74)	-3.37	< 0.00	0.25	0.09, 0.41
Stride length - Right (cm)	121.54 (13.01)	125.76 (13.70)	-4.22	< 0.00	0.31	0.14, 0.49
	Model 1	Model3				
GaitRite® Parameters	Mean (sd)	Mean (sd)	Difference	p-value	Cohen's d	95% CI
Velocity (cm/s)	102.97 (17.65)	110.86 (17.8)	-7.88	< 0.00	0.44	0.22, 0.66
<i>Stride-to-stride average</i>						
Step time - Left (sec)	0.60 (0.06)	0.58 (0.06)	0.02	< 0.00	-0.27	-0.43, -0.10
Step time - Right (sec)	0.60 (0.08)	0.57 (0.05)	0.03	< 0.00	-0.40	-0.74, -0.05
Stance - Right (sec)						
Double support time - Left (sec)						
Stride length - Left (cm)	121.86 (13.11)	127.17 (13.37)	-5.31	< 0.00	0.40	0.19, 0.61
Stride length - Right (cm)	121.54 (13.01)	126.94 (13.56)	-5.40	< 0.00	0.41	0.18, 0.63

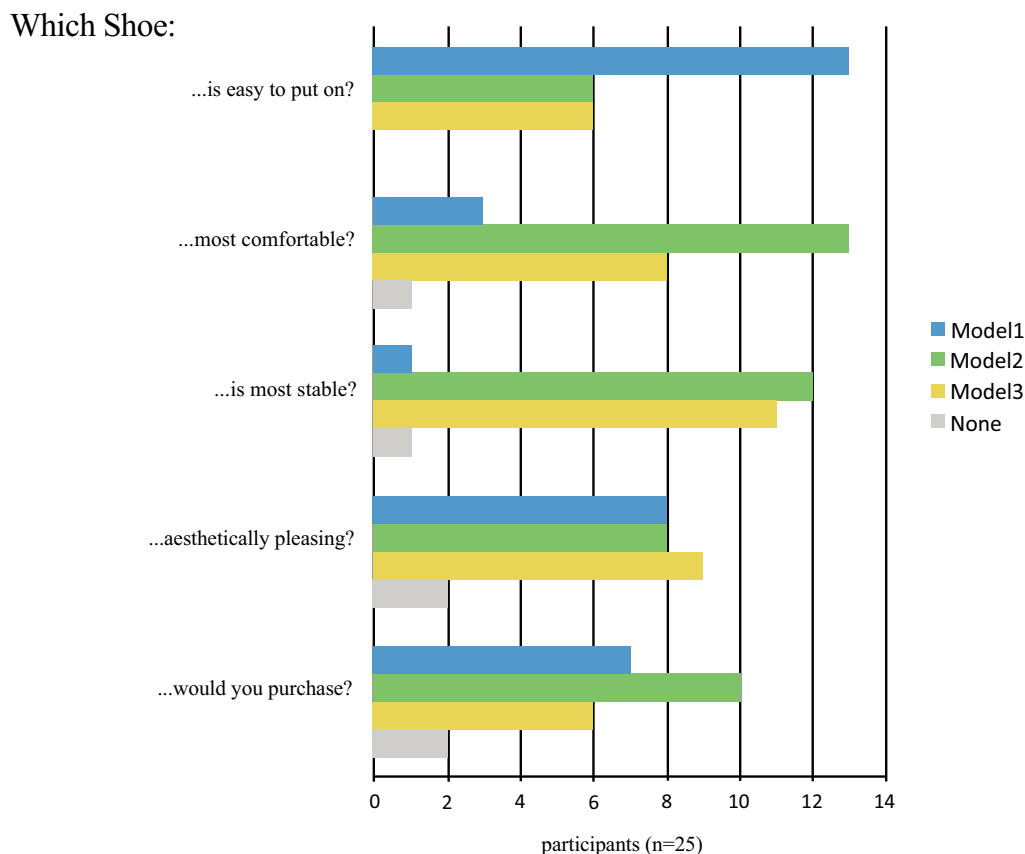
#### 3.2. Acceptability

Fig. (2) shows the results of the participants' ratings for personal preference and experience with different models. Model 2 was best accepted, and had the highest rating for comfort.

Ten persons had some physical difficulties when using the Velcro system.

### 4. DISCUSSION

This study compared the effects of three different shoe models for indoor use, including an open heel shoe, on gait parameters associated with falls in older people, using an electronic walkway system.



**Fig. (2).** Participants' opinions on comfort and aesthetics of the 3 shoe models.

The two high collar shoe models (model 2 and model 3) performed significantly better than the open heel shoe model (model 1) with respect to gait parameters known to increase fall risk. Gait velocity and stride length were significantly reduced when wearing the open heel shoe model compared to the high collar shoe models. Step time, stance, and double support time increased significantly when wearing the open heel shoe model compared to the high collar shoe models. This implies that with regard to fall risk [16, 17, 19, 20] a high collar shoe model should be preferred to an open heel shoe model.

Thus it appears that the preferred and commonly worn open heel shoe model for use in and around the home affects gait characteristics in such a way, that it is likely to increase fall risk. As most falls in older persons in the Netherlands have been shown to occur in and around the home [4], the question arises whether the high number of falls in and around the home might be due, in part, to inappropriate footwear worn at home [5].

#### 4.1. Strengths and Weaknesses of the Study

The strength of this study is that we provided the participants with standardized shoe models to control for specific footwear characteristics. This increases the information about shoe characteristics and their effects on gait parameters, and should improve generalisability of the results.

This study has several limitations. Firstly, sampling error could have influenced our results since the participants were volunteers and information about their health status is lacking. However, we expect that the hazardous effects of the open heel shoe model on gait parameters reported here might be magnified if applied to less able older people. Secondly, the findings should be treated with caution when applied to real life situations, since the testing was conducted in a shoe store where participants walked on an electronic walkway, *i.e.*, on a flat surface. However, we think that in real life situations in and around the home, the differences in gait characteristics might be even more pronounced.

#### 4.2. Comparison With Other Studies

As far as we are aware from the literature, this is the first study to test and demonstrate the effects of three specific

shoe models on gait parameters associated with fall risk in community-dwelling older persons, as measured with an electronic walkway. Also, we believe it is the first study to include an open heel shoe model in the comparison.

We found only one study measuring the effect of textured insoles in community-dwelling older fallers with an electronic walkway system; this study showed a negative effect on gait parameters associated with falls, *i.e.*, wearing the textured insoles led to a significantly lower gait velocity, step length, and stride length compared with wearing smooth insoles [21]. The difference between this study and the current study is that in our study, a history of falls was not an inclusion criterion.

## CONCLUSION AND IMPLICATIONS

In conclusion, the current study demonstrates that wearing an open heel shoe model is associated with gait parameters that have been shown to be associated with fall risk, compared with a high collar shoe model, in community-dwelling independent older persons.

Further research is needed to identify the specific shoe characteristics that provide the greatest benefits for safety and comfort, especially for footwear worn in and around the home.

## DECLARATION OF SOURCES OF FUNDING

This work was supported by the Foundation for Quality of Life in Ageing. The Foundation for Quality of Life in Ageing funded a travel grant for AH to travel between Delft University of Technology and the Intersko Shoe Company in Voorburg.

## CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

## ACKNOWLEDGEMENTS

We thank Marcel van t Hoff, Intersko Company, Voorburg, The Netherlands, for providing the shoe models. Marcel van t Hoff had no involvement in the study design, in the collection, analysis and interpretation of data, in the writing of the manuscript, and in the decision to submit the manuscript for publication.

## REFERENCES

- [1] Campbell AJ, Borrie MJ, Spears GF, Jackson SL, Brown JS, Fitzgerald JL. Circumstances and consequences of falls experienced by a community population 70 years and over during a prospective study. *Age Ageing* 1990; 19(2): 136-41. [<http://dx.doi.org/10.1093/ageing/19.2.136>] [PMID: 2337010]
- [2] Tinetti ME, Williams CS. Falls, injuries due to falls, and the risk of admission to a nursing home. *N Engl J Med* 1997; 337(18): 1279-84. [<http://dx.doi.org/10.1056/NEJM199710303371806>] [PMID: 9345078]
- [3] Tromp AM, Pluijm SM, Smit JH, Deeg DJ, Bouter LM, Lips P. Fall-risk screening test: a prospective study on predictors for falls in community-dwelling elderly. *J Clin Epidemiol* 2001; 54(8): 837-44. [[http://dx.doi.org/10.1016/S0895-4356\(01\)00349-3](http://dx.doi.org/10.1016/S0895-4356(01)00349-3)] [PMID: 11470394]
- [4] Veiligheid NL. Valongevallen 65-plussers 2013 [Retrieved from the website of VeiligheidNL]; Available from: <http://www.veiligheid.nl/csi/veiligheidnl.nsf/content/brongegevens-onderzoek>. [2014 February 26];
- [5] Oei BH. Design of footwear for the prevention of falls among seniors: Final Master project Faculty Industrial Design Engineering. Delft, The Netherlands: Delft University of Technology 2005.
- [6] Easington primary care trust. 'Sloppy slipper' scheme cuts old people's falls. 2003 [Retrieved from the website of the Guardian]; Available from: <http://www.theguardian.com/society/2003/dec/23/longtermcare> [2014 March 21];
- [7] Kerse N, Butler M, Robinson E, Todd M. Wearing slippers, falls and injury in residential care. *Aust N Z J Public Health* 2004; 28(2): 180-7. [<http://dx.doi.org/10.1111/j.1467-842X.2004.tb00933.x>] [PMID: 15233359]
- [8] Boelens C, Hekman EE, Verkerke GJ. Risk factors for falls of older citizens. *Technol Health Care* 2013; 21(5): 521-33. [PMID: 24077498]
- [9] Gabell A, Simons MA, Nayak US. Falls in the healthy elderly: predisposing causes. *Ergonomics* 1985; 28(7): 965-75. [<http://dx.doi.org/10.1080/00140138508963219>] [PMID: 4043031]
- [10] Koepsell TD, Wolf ME, Buchner DM, *et al.* Footwear style and risk of falls in older adults. *J Am Geriatr Soc* 2004; 52(9): 1495-501. [<http://dx.doi.org/10.1111/j.1532-5415.2004.52412.x>] [PMID: 15341551]

- [11] Menz HB, Morris ME, Lord SR. Footwear characteristics and risk of indoor and outdoor falls in older people. *Gerontology* 2006; 52(3): 174-80.  
[<http://dx.doi.org/10.1159/000091827>] [PMID: 16645298]
- [12] Lord SR, Bashford GM. Shoe characteristics and balance in older women. *J Am Geriatr Soc* 1996; 44(4): 429-33.  
[<http://dx.doi.org/10.1111/j.1532-5415.1996.tb06416.x>] [PMID: 8636591]
- [13] Lord SR, Bashford GM, Howland A, Munroe BJ. Effects of shoe collar height and sole hardness on balance in older women. *J Am Geriatr Soc* 1999; 47(6): 681-4.  
[<http://dx.doi.org/10.1111/j.1532-5415.1999.tb01589.x>] [PMID: 10366166]
- [14] Arnadottir SA, Mercer VS. Effects of footwear on measurements of balance and gait in women between the ages of 65 and 93 years. *Phys Ther* 2000; 80(1): 17-27.  
[PMID: 10623957]
- [15] Stephen DG, Wilcox BJ, Niemi JB, Franz JR, Kerrigan D, DAndrea SE. Baseline-dependent effect of noise-enhanced insoles on gait variability in healthy elderly walkers. *Gait Posture* 2012; 36(3): 537-40.  
[<http://dx.doi.org/10.1016/j.gaitpost.2012.05.014>] [PMID: 22739049]
- [16] Sterke CS, van Beeck EF, Looman CW, Kressig RW, van der Cammen TJ. An electronic walkway can predict short-term fall risk in nursing home residents with dementia. *Gait Posture* 2012; 36(1): 95-101.  
[<http://dx.doi.org/10.1016/j.gaitpost.2012.01.012>] [PMID: 22386897]
- [17] Verghese J, Holtzer R, Lipton RB, Wang C. Quantitative gait markers and incident fall risk in older adults. *J Gerontol A Biol Sci Med Sci* 2009; 64(8): 896-901.  
[<http://dx.doi.org/10.1093/gerona/glp033>] [PMID: 19349593]
- [18] McDonough AL, Batavia M, Chen FC, Kwon S, Ziai J. The validity and reliability of the GAITRite systems measurements: A preliminary evaluation. *Arch Phys Med Rehabil* 2001; 82(3): 419-25.  
[<http://dx.doi.org/10.1053/apmr.2001.19778>] [PMID: 11245768]
- [19] Hausdorff JM, Rios DA, Edelberg HK. Gait variability and fall risk in community-living older adults: a 1-year prospective study. *Arch Phys Med Rehabil* 2001; 82(8): 1050-6.  
[<http://dx.doi.org/10.1053/apmr.2001.24893>] [PMID: 11494184]
- [20] McGough EL, Logsdon RG, Kelly VE, Teri L. Functional mobility limitations and falls in assisted living residents with dementia: physical performance assessment and quantitative gait analysis. *J Geriatr Phys Ther* 2013; 36(2): 78-86.  
[<http://dx.doi.org/10.1519/JPT.0b013e318268de7f>] [PMID: 22976811]
- [21] Hatton AL, Dixon J, Rome K, Newton JL, Martin DJ. Altering gait by way of stimulation of the plantar surface of the foot: the immediate effect of wearing textured insoles in older fallers. *J Foot Ankle Res* 2012; 5: 11.  
[<http://dx.doi.org/10.1186/1757-1146-5-11>] [PMID: 22546376]
- [22] Kressig RW, Beauchet O. Guidelines for clinical applications of spatio-temporal gait analysis in older adults. *Aging Clin Exp Res* 2006; 18(2): 174-6.  
[<http://dx.doi.org/10.1007/BF03327437>] [PMID: 16702791]
- [23] Cohen J. *Statistical power analysis for the behavioral sciences*. 2<sup>nd</sup> ed. Hillsdale, New Jersey: Lawrence Earlbaum Associates 1988.