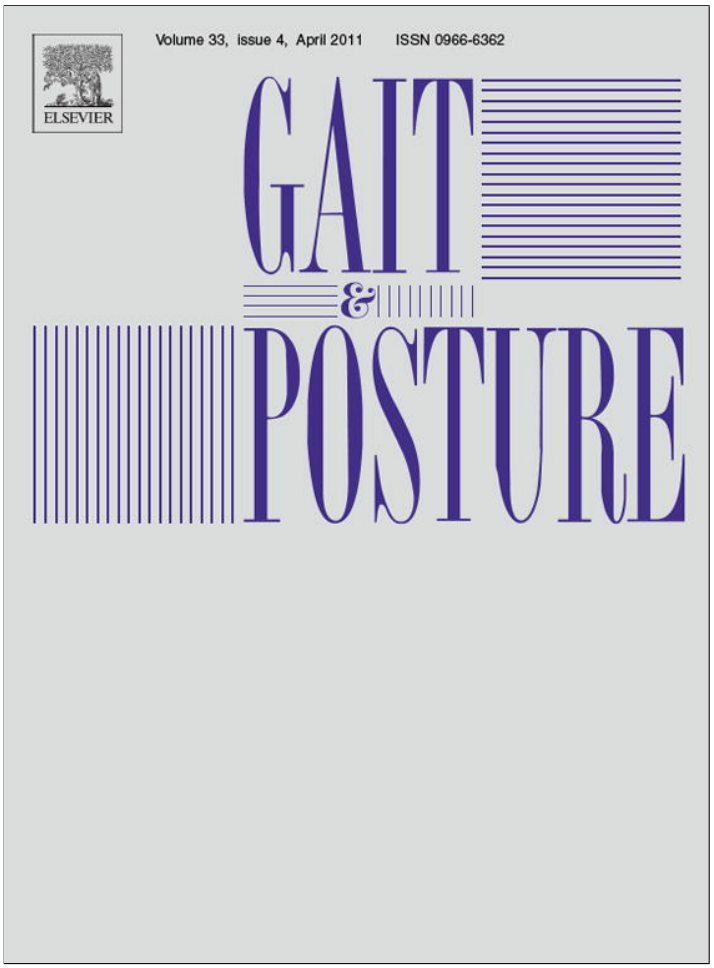

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Short communication

# Slip resistance of non-slip socks – An accelerometer-based approach

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ABSTRACT

The present study investigated the relative slip resistance of commercially available non-slip socks during gait. Twenty-four healthy subjects (29.3 ± 10.4 years) participated in the study. Each subject completed 4 different test conditions (barefoot, non-slip socks, conventional socks, backless slippers) in a randomized, balanced order. The slip resistance was estimated by measuring the heel deceleration time using a heel-mounted accelerometer. Repeated measures ANOVA and post hoc paired-sample *t*-test with Bonferroni correction were used for statistical analysis. Compared to barefoot walking absolute deceleration times [ms] were significantly increased when wearing conventional socks or slippers. No significant differences were observed between the barefoot and non-slip socks conditions. The present study shows that non-slip socks improved slip-resistance during gait when compared to conventional socks and slippers. Future investigations should verify the present findings in hospital populations prone to slip-related falls.


## 1. Introduction

Accidental falls related to slipping are a major health problem in hospital inpatients, with estimated rates ranging from 3 to 4 falls per 1000 occupied bed days (OBDs) on general acute care hospital units to 17–67 OBDs on some psychogeriatric units [1]. Even though non-slip socks have been suggested as a simple and effective method to prevent falls in hospitals [2], their effectiveness in terms of slip-resistance has recently been questioned as some of them showed poorer performance than barefoot during an inclined ramp test [3]. However, even though most falls occur when patients are ambulating [4], no study has yet investigated the slip-resistant properties of non-slip socks during human gait. A practical measurement approach for assessing slip resistance during gait is to determine the forward displacement of the heel following heel strike, or slip distance, using a heel-mounted accelerometer [5]. The aim of the present study was to assess the slip resistance of commercially available non-slip socks marketed for use with hospital inpatients compared to other footwear conditions typically encountered in hospitals (i.e. barefoot, conventional socks, slippers) during gait using a heel-mounted accelerometer.

## 2. Methods

Twenty-four healthy subjects [6 women, 18 men; mean age 29.3 years (SD = 10.4 years); mean body mass 81.8 kg (SD = 14.8 kg); mean height 173.2 cm (SD = 13.1 cm)] participated in the study. Each subject denied any neurological or musculoskeletal disability.

Each subject completed 4 different test conditions (barefoot, non-slip socks, conventional socks, backless slippers) in a randomized, balanced order (computer-generated randomization list). The non-slip socks (VITANESS, Germany; material: 90% cotton, 9% polyamide, 1% lycra; thickness: ≈3 mm without grippers) were treaded with 88–94 (depending on sock size) round phthalate-free plastisol grippers which were distributed over the full plantar aspect of the sole. These grippers (thickness: 1–1.5 mm) had diameters of 0.8 cm in the forefoot region and 1.2 cm in the metatarsal and heel region, respectively. The conventional socks (thickness: ≈3 mm) were 65% cotton and 35% polyester. The backless slip-on slippers (without fastenings) had a flat felt outsole with smooth tread. All footwear types were designed to fit both women and men and were provided in 3 different European sizes (35–38, 39–42, 43–46) to ensure the correct fit.

Participants walked along a 12 m linoleum walkway. The central 6 m of the walkway were marked by two lines allowing the participants to get into their stride before the first line and prevent slowing down before the 6 m line. Prior to testing, all subjects performed practice trials at a self-paced speed until they felt comfortable with the walkway and the different footwear conditions. During the experimental gait trials participants ambulated at a walking speed of 1.25 m/s until the desired number of 20 separate strides was reached. A stopwatch was used to verify walking speed, and feedback was provided until speed was consistently within ±5% of the defined walking speed [5]. Gait tests were administered by one trained examiner.

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**Table 1**
Gait characteristics and deceleration time per test condition (mean ± 1SD; 95% CI).

| | Barefoot | Non-slip socks | Socks | Slipper |
|---|---|---|---|---|
| Cycle time [s] | 1.03 ± 0.07 | 1.03 ± 0.07 | 1.01 ± 0.09 | 1.02 ± 0.10 |
| | 1.00–1.06 | 1.00–1.06 | 0.97–1.05 | 0.97–1.06 |
| Cadence [steps/min] | 117 ± 8 | 116 ± 8 | 120 ± 13 | 120 ± 14 |
| | 114–120 | 113–120 | 114–125 | 113–126 |
| Deceleration time [ms] | 17.6 ± 3.1 | 17.8 ± 3.6 | 18.6 ± 3.5 | 19.8 ± 5.0 |
| | 16.3–18.9 | 16.3–19.4 | 17.2–20.1 | 17.6–21.9 |

A small 1-directional accelerometer (Biovision, Wehrheim, Germany), aligned posterior on the medial axis of the subjects' right calcaneus [6,7], was used for unilateral recordings. In order to relate the accelerometer data to the instant of heel-strike pressure sensitive footswitches were secured at both heels. Accelerometer and foot contact data were collected for each subject using a multi-channel datalogger system (Biovision, Wehrheim, Germany) operating at 2000 Hz per channel. The obtained accelerometer signals were visually controlled and filtered using a low-pass, zero-lag, critical damped, fourth order filter (10 Hz cut-off) to allow smoothing without introducing any time delay.

Heel strike was determined by the footswitch signal ipsilateral to the recording site and used to define the start/stop of each cycle and to calculate absolute deceleration times [ms] per gait cycle. Heel deceleration time was defined as the time period from heel strike to the first zero crossing of the forward acceleration signal, i.e. the transition from acceleration to deceleration [5]. Further analysis focused on the heel deceleration time, the best estimate of slip distance ($R^2 = 0.511$) [5]. All signals were visually inspected to assure that no footswitch triggering occurred prior to floor contact especially during the backless slipper condition. Due to footswitch artefacts in two subjects, a minimum of 15 instead of the initially planned 20 successful walking cycles had to be used to calculate the mean deceleration value for every subject and test condition. Data was processed using LabView (National Instruments, Austin, TX, USA) and SOLEASY (ALEA Solutions, Zurich, Switzerland).

A repeated measures analysis of variance (ANOVA) was used to compare cycle duration, cadence and deceleration time between the different footwear conditions. Student's paired samples *t*-test with Bonferroni correction was used for post hoc analysis. A two-sided $p$ value of less than 0.05 was considered as statistically significant. All statistical computations were made with SPSS (SPSS Inc., Chicago, IL, USA).

## 3. Results

Group averages of gait characteristics and deceleration time for all test conditions are given in Table 1. No significant differences in cycle time or cadence were observed. ANOVA for repeated measures revealed significant ($p < .01$) differences in absolute deceleration times [ms] between test conditions. Compared to barefoot walking horizontal slide durations were significantly increased when wearing conventional socks or slippers. No significant differences to barefoot walking were obtained during the non-slip socks condition ($p > .05$). Fig. 1 indicates the relative increase in deceleration times in comparison to barefoot ambulation.

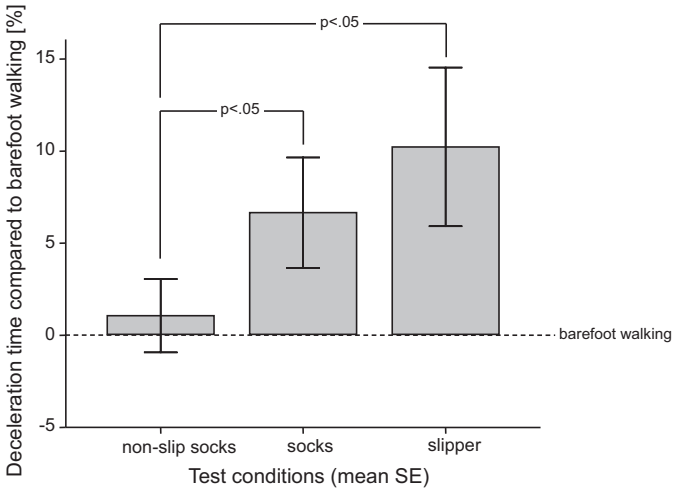


**Fig. 1.** Relative increase in deceleration times in comparison to barefoot walking.

## 4. Discussion

The prevention of falls due to slipping is a key challenge for geriatrics, and particularly in hospitals. Since the poor grip or low friction between the footwear or foot and an underlying surface is considered the primary risk factor for slipping [8], footwear provision has been included as point of good practice and as a common component of successful multifactorial interventions [1]. However, compliance problems must be taken into account as hospital inpatients often tend to ambulate either wearing socks or slippers instead of adequate footwear. Non-slip socks might help to overcome non-compliance with adequate footwear and have been suggested as a simple and effective measure to prevent falls in hospitals [2]. However, recent research failed to demonstrate adequate slip-resistance of non-slip socks compared to barefoot and conventional socks in healthy adults [3]. These results deviate from our findings showing that non-slip socks provided slip-resistance comparable to barefoot and better than conventional socks or backless slippers. There are several explanations that might account for this discrepancy. First, it might be due to variations in slippage characteristics of the different footwear conditions among the different test procedures [3]. In our study slip resistance was assessed during gait whereas Chari et al. [3] collected slippage data with participants in a static standing position on an inclined plane. Second, it is conceivable that different socks might have different anti-resistant properties, indicating the necessity of individually testing several products. Third, the non-slip socks were tested on surfaces with different frictional properties. Chari et al.'s study [3] tested slip resistance on vinyl floor, whereas in our study socks were tested on linoleum. This consideration might lead to the conclusion that non-slip socks should be tested on all relevant surfaces commonly found in hospitals (e.g. vinyl, linoleum, tile, polished concrete).

Besides slip-resistance, it can be speculated that the mechanisms underlying the effect of the non-slip socks might be attributed to enhanced sensory information on the soles of the feet. Whereas the smooth conventional socks and slipper insoles may dampen sensory information, it is conceivable that the grippers at the sole of the non-slip socks provide tactile stimulation to plantar mechanoreceptors leading to altered gait pattern and heel deceleration similar to barefoot walking.

It should be considered that the difference in heel deceleration noted between the backless slipper and the other conditions could be due to factors other than the slip-resistance of the slipper sole. More specifically, the backless aspect of the slipper might have lead to different gait patterns and lower limb biomechanics, aimed at keeping the slipper "on" during walking (toe clawing action) compared to the barefoot and sock conditions.

The results of the present study cannot be extrapolated to the hospital environment unrestrictedly as we included young healthy subjects only. It is conceivable that age and/or disease related differences in some intrinsic factors such as foot anatomy, physical

performance capacity (e.g. strength, balance, sensorimotor control), and gait biomechanics [8,9] might yield different results. Furthermore, it remains to be elucidated whether the slip-resistant properties of non-slip socks tested in the laboratory would prevent patients from falling during real-life slipping events in the hospital environment. Nevertheless, our results are promising as they showed improved slip-resistance when compared to conventional socks and slippers, i.e. footwear conditions typically found in hospitals. Thus, future investigations should verify the present findings in various hospital populations prone to slip-related falls (e.g. frail older patients or patients with mental disorders) and, if reproducible, assess the effectiveness of non-slip socks, implemented in routine hospital care, in preventing falls and fall-related injuries. In summary, the main finding of our study was that non-slip socks can provide suitable slip-resistance during gait. Since adequate footwear provision is currently considered best practice treatment, hospital inpatients should be encouraged to ambulate in appropriate shoes [10] where possible and otherwise wear non-slip socks instead of conventional socks or slippers. Even though the potential clinical benefit of the non-slip socks might be questioned since they do not appear to reduce slip propensity better than barefoot, our conclusion seems valid due to the following reason. Elderly persons frequently complain about cold feet and choose to wear conventional socks or slippers instead of walking barefoot which might lead to increased fall risk.

## Acknowledgment

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## Conflict of interest

The non-slip socks used in this study were provided by Vitaness (Germany). The study was investigator initiated; Vitaness did not provide any additional financial support to the research in this paper and had no control over the decision to approve or submit the manuscript for publication.

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