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Ulrich Lindemann[1,2] · Michael Schwenk[1,3] · Syn Schmitt[2,4] · Michael Weyrich[2,5] · Wolfgang Schlicht[2,6] · Clemens Becker[1,2]

[1] Department of Geriatrics and Clinic for Geriatric Rehabilitation, Robert-Bosch-Hospital, Stuttgart, Germany
[2] Research Initiative Human Factors in Ageing, Technology and Environment, University Stuttgart, Stuttgart, Germany
[3] Network on Aging Research, University of Heidelberg, Heidelberg, Germany
[4] Institute of Sports and Movement Science, University of Stuttgart, Stuttgart, Germany
[5] Institute for Automation and Software Engineering, University of Stuttgart, Stuttgart, Germany
[6] Department of Sport and Exercise Science, Chair Exercise and Health Sciences, University of Stuttgart, Stuttgart, Germany

Effect of uphill and downhill walking on walking performance in geriatric patients using a wheeled walker

The study aimed to describe changes of walking performance in older persons when ambulating with a wheeled walker in a challenging environment. The results are relevant to quantify a possible effect of the environment and to develop a test protocol for smart wheeled walkers which may overcome the challenges. Furthermore, the use of a wheeled walker was investigated with regard to the dual task paradigm in novice wheeled walker users. This might be relevant for initially providing wheeled walkers to older persons.

Introduction

Walking performance decreases with age, which can be described by a decrease of gait speed [2]. In order to prevent falls [7] and/or to improve participation in daily life [14] older persons are supplied with wheeled walkers (WW). Besides positive effects on gait when using a WW [1, 15], environment-related conditions can cause serious problems, e. g. when opening and passing through a door [9]. Other common environmental conditions are inclined surfaces, which require uphill and downhill walking. Recent study results suggest that WW users experience problems during uphill and downhill walking [9]; however, these results are limited to subjective interviews. Objective data on the effect of uphill and downhill walking on walking performance in older adults are lacking.

In general, lack of environmentalal fit can hinder accessibility and participation [3, 6] in WW users. A deterioration of walking performance when using a WW can also be attributed to certain diseases, e. g. Parkinson's disease [3, 4]. Furthermore, at least in novice WW users a motor dual-task paradigm can be applied, which has been shown to decrease walking performance in older persons [11].

Smart WWs are developed and equipped with technology to improve their usability, but basic knowledge about how and where WWs are helpful is still lacking. Technical solutions are driven by engineering expertise rather than patient-centered knowledge of changes in walking performance related to WWs usage. Walking performance can be affected in terms of functional capacity during unimpeded walking as indicated by reduced gait speed and/or quality of walking. Standardized test batteries including various relevant aspects of walking performance and accessibility in order to assess the smart WW's usability are not available. Recently developed smart walkers focus on obstacle avoidance, powered impulsion and navigation technology [12, 19, 20]. Another aspect lacking in WW research and development is the use of human body models. Stunningly fast development in simulation technology has produced physiologically detailed models of the full human activated by muscle-like drives [13]. These models are able to perform human-like movement. At present, computer models of WWs, ready to be implemented in human body modelling and simulation frameworks are not available.

The aim of the study was to compare uphill and downhill walking with walking level when using a standard WW under both conditions. A second aim was to investigate the effect of using a standard WW walking level in ambulatory geriatric patients compared to unassisted walking. The rationale for the study was to identify possible problems when using a WW. We hypothesized that uphill and downhill walking with a WW decreases

Table 1 Description of all ($n = 20$) included patients (70% women)

	Median	IQR	Min–Max
Age (years)	84.5	78.25–87.75	75–95
Body mass (kg)	63	52.8–68	49–102
Height (cm)	163	155–171	148–176
Body mass index (kg/m^2)	23.1	22.1–26.1	19.4–32.9
Comorbidity (*0*–18)	3	2.3–4.8	0–7
Habitual gait speed (m/s)	1.12	1.0–1.23	0.8–1.37

Comorbidity assessed by the functional comorbidity index, best score value is in italics
IQR interquartile range

walking performance when compared to walking level with a WW. Additionally, we hypothesized that the use of a WW decreases walking performance with regard to a dual-task paradigm, when a person usually does not need a walking aid when walking level.

Methods

Subjects and design

For this experimental cross-sectional study with different test conditions 20 sub-acute patients (median age 84.5 years, 70% women) were recruited from a geriatric rehabilitation clinic in the southwest of Germany. As this study with pilot character was conducted in order to prepare the methods and procedures of a larger study, including several problems of WW use, the number of patients was predetermined pragmatically [18]. All patients were 75 years old or older and did not use any walking aid in normal life or during their rehabilitation. The rationale for these criteria was the inclusion of a potential user group (health affected older persons) and the possibility to investigate the dual-task paradigm (novice users). Exclusion criteria were unilateral functional impairment, such as stroke or recent hip replacement and inability to follow verbal instructions. The study was approved by the ethical committee of the University of Tübingen (241/2015BO1). All participants gave written informed consent.

Procedures

The patients walked with their habitual pace along a level surface, uphill and downhill, all conditions without and with a standard WW (Ideal, Meyra, Kalletal-Kalldorf, Germany) with 4 wheels, of which the 2 front wheels were 360° rotatable. All patients used the same WW of 9.5 kg weight. Gait analyses were performed on a 10 m long continuously level path followed by a 10 m long continuously 8% inclining path as part of the "patient garden" in the hospital environment. The slope of 8% in our study was chosen for pragmatic reasons. This frequently visited part of the "patient garden" was located near the hospital and the level path was directly followed by the uphill/downhill path. Two trials of each condition were performed and the order of the test conditions was randomized.

Outcome parameters

In order to assess gait speed and quality of walking performance the patients were equipped with 3 OPAL sensors (APDM, Portland, USA), fixed with a belt or elastic straps at the lower back (L4-5) and frontal to the left and right ankle joints. The OPAL sensors include accelerometers, gyroscopes and magnetometers, each 3-axial. Gait speed (m/s), stride length (m) and cadence (steps/min), were used to describe walking performance as recommended [10]. In addition, the walk-ratio (i. e. step length/cadence) was calculated as a global descriptive parameter of the walking pattern [16]. With regard to walking capacity and quality of walking, gait speed and the walk-ratio were taken as main endpoints, respectively. Stride length and cadence were taken as explanatory variables. All outcome parameters were taken from the second trial at each test condition in order to standardize for a possible learning effect.

Descriptive parameters

Habitual gait speed (m/s) of level walking was used as a functional descriptive parameter. Furthermore, the patients were screened for comorbidities using a questionnaire [8] in a standardized interview.

Statistics

Due to the small sample size, median and interquartile range (IQR), as well as non-parametric tests (Wilcoxon) were used to describe parameters and differences between conditions, respectively, and all analyses were performed in one group. The significance level of all statistical tests to compare the two main endpoints (i.e. gait speed and walk-ratio) was therefore adjusted to multiple testing and was set to $\alpha = 2.5\%$ (two-sided). All analyses were conducted using SPSS version 16 software (SPSS, Chicago, IL).

Results

All contacted patients were willing to participate and none of these had to be excluded. The median age of those was 84.5 years (IQR 78.25–87.75 years) and median habitual gait speed was 1.12 m/s (IQR 1.0–1.23 m/s). The cohort is described in detail in **Table 1**.

When compared to walking level with a WW, uphill walking with a WW was slower (median values 0.79 m/s versus 1.07 m/s, $p < 0.001$) and had a worse walk-ratio of 0.54 m/(steps/min) versus 0.58 m/(steps/min) ($p = 0.023$) with decreased stride length (1.01 m versus 1.25 m, $p < 0.001$) and cadence (94 steps/min versus 108 steps/min, $p < 0.001$). When compared to walking level with a WW, downhill walking with a WW did not affect gait speed but decreased stride length (1.19 m versus 1.25 m, $p = 0.029$) and increased cadence (111 steps/min versus 108 steps/min, $p = 0.008$) resulting in a worse walk-ratio with 0.55 m/(steps/min) versus 0.58 m/(steps/min) ($p = 0.001$).

The change of median gait speed resulting from the comparison between level and uphill walking was 17%without a WW but was 26% when using the WW. For downhill walking the respec-

Abstract · Zusammenfassung

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Effect of uphill and downhill walking on walking performance in geriatric patients using a wheeled walker

Abstract

Background. Wheeled walkers are recommended to improve walking performance in older persons and to encourage and assist participation in daily life. Nevertheless, using a wheeled walker can cause serious problems in the natural environment. This study aimed to compare uphill and downhill walking with walking level in geriatric patients using a wheeled walker. Furthermore, we investigated the effect of using a wheeled walker with respect to dual tasking when walking level.

Methods. A total of 20 geriatric patients (median age 84.5 years) walked 10 m at their habitual pace along a level surface, uphill and downhill, with and without a standard wheeled walker. Gait speed, stride length and cadence were assessed by wearable sensors and the walk ratio was calculated.

Results. When using a wheeled walker while walking level the walk ratio improved (0.58 m/[steps/min] versus 0.57 m/[steps/min], $p = 0.023$) but gait speed decreased (1.07 m/s versus 1.12 m/s, $p = 0.020$) when compared to not using a wheeled walker. With respect to the walk ratio, uphill and downhill walking with a wheeled walker decreased walking performance when compared to level walking (0.54 m/[steps/min] versus 0.58 m/[steps/min], $p = 0.023$ and 0.55 m/[steps/min] versus 0.58 m/[steps/min], $p = 0.001$, respectively). At the same time, gait speed decreased (0.079 m/s versus 1.07 m/s, $p < 0.0001$) or was unaffected.

Conclusion. The use of a wheeled walker improved the quality of level walking but the performance of uphill and downhill walking was worse compared to walking level when using a wheeled walker.

Keywords

Downhill walking · Uphill walking · Geriatric patients · Wheeled walker · Walk ratio

Effekt von Bergauf- und Bergabgehen auf die Gehfähigkeit geriatrischer Patienten mit Rollator

Zusammenfassung

Hintergrund. Rollatoren werden im Alter zur Stabilisierung des Gangbildes und zur Verbesserung der Teilhabe genutzt. Der Gebrauch von Rollatoren kann aber auch zu erheblichen Problemen führen, wenn die Umgebungspassung nicht gegeben ist. Das Gangbild geriatrischer Patienten mit Rollator beim Bergauf- und Bergabgehen sollte mit dem Gangbild in der Ebene verglichen werden. Weiterhin sollte der Effekt der Nutzung eines Rollators unter dem Aspekt der geteilten Aufmerksamkeit in der Ebene untersucht werden.

Methoden. Zwanzig geriatrische Patienten (mittleres Alter: 84,5 Jahre) gingen mit und ohne Rollator 10 m auf einer ebenen Strecke, bergauf und bergab. Dabei wurden Gehgeschwindigkeit, Schreitlänge und Schrittfrequenz mit am Körper getragenen Sensoren gemessen. Aus Schreitlänge und Schrittfrequenz wurde die Walk-Ratio berechnet.

Ergebnisse. Verglichen mit Gehen ohne Rollator verbesserte der Gebrauch eines Rollators die Walk-Ratio (0,58 m/[Schritte/min] vs. 0,57 m/[Schritte/min]; $p = 0{,}023$), wohingegen die Gehgeschwindigkeit mit Rollator reduziert war (1,07 m/s vs. 1,12 m/s; $p = 0{,}020$). Beim Bergauf- und Bergabgehen mit Rollator war die Walk-Ratio schlechter als beim Gehen mit Rollator in der Ebene (0,54 m/[Schritte/min] vs. 0,58 m/[Schritte/min]; $p = 0{,}023$ und 0,55 m/[Schritte/min] vs. 0,58 m/[Schritte/min]; $p = 0{,}001$). Gleichzeitig war die Gehgeschwindigkeit beim Bergaufgehen langsamer im Vergleich zur Ebene (0,079 m/s vs. 1,07 m/s; $p < 0{,}0001$) und zeigte beim Bergabgehen keinen Effekt.

Schlussfolgerung. Der Gebrauch eines Rollators verbesserte das Gangbild in der Ebene. Dem gegenüber verschlechterte sich das Gangbild beim Gebrauch eines Rollators beim Bergauf- und Bergabgehen verglichen mit dem Gehen in der Ebene mit Rollator.

Schlüsselwörter

Bergabgehen · Bergaufgehen · Geriatrische Patienten · Rollator · Walk-Ratio

tive results were 4% without a WW and 8% when using the WW. The change of the median walk-ratio resulting from the comparison between level and uphill walking was 7% when using a WW but there was no change without using the WW. For downhill walking the respective results were 4% without a WW and 5% when using the WW.

With regard to the walk-ratio, the walking pattern improved on level surfaces when using a WW when compared to walking without a walking aid with median values of 0.58 m/(steps/min) versus 0.57 m/(steps/min) ($p = 0.023$). At the same time gait speed and cadence decreased (1.07 m/s versus 1.12 m/s, $p = 0.020$ and 108 steps/min versus 111.5 steps/min, $p = 0.018$, respectively) with stride length statistically not affected. All results of walking performance at different test conditions are presented in detail in **Table 2**.

Discussion

Confirming our hypothesis, performance of uphill and downhill walking deteriorated when using a WW compared to walking level with a WW. These results are in line with a survey identifying uphill and downhill walking with WWs as a problem of WW users [9]. Not surprisingly, gait speed decreased when walking uphill without a WW compared to level walking without a WW but the general effect of uphill walking resulting in slower gait speed was increased even further when using a WW, possibly by the additional weight of the WW being pushed uphill. Quality of walking performance was also negatively affected as expressed by a decrease in the walk-ratio indicating a higher risk of falling [5]. Here, the negative effect of uphill walking on the walk-

Table 2 Results of walking performance of all (*n* = 20) patients at different test conditions

	Gait speed (m/s)	Stride length (m)	Cadence (steps/min)	Walk-ratio (m/[steps/min])
	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)
Walking level without WW	1.12 (1.0–1.23)[a]	1.23 (1.12–1.31)	111.5 (103.5–117)[a]	0.57 (0.49–0.6)[a]
Walking level with WW	1.07 (0.99–1.16)	1.25 (1.12–1.27)	108 (97.7–113.8)	0.58 (0.53–0.63)
Uphill walking without WW	0.93 (0.79–1.05)[b]	1.13 (1.0–1.17)[b]	102 (97.2–110.5)[b]	0.57 (0.47–0.6)
Uphill walking with WW	0.79 (0.74–0.89)[a]	1.01 (0.91–1.12)[a]	94.3 (86.5–103)[a]	0.54 (0.48–0.62)[a]
Downhill walking without WW	1.16 (0.99–1.26)	1.23 (1.11–1.33)	112.5 (103.5–121.5)	0.55 (0.49–0.6)
Downhill walking with WW	1.11 (0.97–1.15)	1.19 (1.13–1.26)[a]	111 (102–120.3)[a]	0.55 (0.48–0.6)[a]

IQR interquartile range, *WW* wheeled walker
[a] indicates statistical difference from walking level with wheeled walker
[b] indicates statistical difference from walking level without wheeled walker

ratio was smaller but was also strengthened by using the WW. A smart WW recognizing the incline could add propulsion technology to reduce the decrease in walking performance and thus, hopefully, would decrease the risk of falling. In contrast, a possible dependence on the assistive device could be seen as a negative effect of a smart WW.

A smart WW could reduce the decrease in walking performance. Although gait speed was not affected by walking downhill compared to walking level when using a WW, there was a statistically significant decrease in quality of walking (walk-ratio), which was depicted by a simultaneous increase of cadence and decrease of stride length. Again, the general negative effect of walking downhill on walking performance without using a WW increased when using a WW. These results are also in line with the survey mentioned previously [9] and confirm our hypothesis. Here, a smart WW recognizing the downhill condition could add a sliding break to counteract the gravitational pull of the WW. In contrast, our hypothesis was not confirmed with regard to the use of a WW in novice users while walking on a level surface. Using the WW, an increase of the walk-ratio by a decreased cadence with unaffected stride length indicates a better quality of walking with calming down walking. In our study this is supported by the decrease in gait speed and it might be supported by lower electromyographic activity of lower limb muscles, which was shown in another study [17]. Although a median habitual gait speed of 1.12 m/s may represent a relatively good walking capability, these older persons still were geriatric patients with some health-related problems. At least for unimpeded walking along a level surface these novice WW users seemed to benefit from using a WW. In this condition the assumed negative effect of the motor dual-task [11] was not effective or was counteracted by the described benefit. A more complex task of WW use, e. g. turning on the spot, may show other results, at least in novice WW users. The ecological validity of these dual-task test conditions, combining cognitive and motor performance in the real environment, is more likely given than under non-realistic test conditions, such as walking with a WW and simultaneously counting backwards.

A test battery to investigate the usability and effectiveness of a smart WW should include uphill and downhill walking as it identified problems in our study when using a standard WW. Using human body models including a specific or various WW models could add to a better test battery in an early stage of development. Using such models to study the interaction of humans and WWs would allow a better understanding of the effect of WWs on human movement and for a tailoring of WWs to the user needs.

Because of the small sample size and the explorative character of the study it is a limitation of our study that the results cannot be generalized to other cohorts. The walk-ratio, which was used to describe quality of walking, is not widely used at present. Although the clinical relevance of small differences is not clear, in our study the results in the walk-ratio were explained by changes in widely accepted parameters, such as stride length and cadence. As one of our interests was a possible effect of a motor dual-task, only novice WW users were included. Furthermore, only one of the a priori known problems was approached in this experimental study. Future studies should include long-time WW users and should investigate more of these problems to provide further parts of a test battery to investigate the usability and effectiveness of smart WWs.

Conclusion

- **The use of a WW improves the quality of level walking in ambulatory novice users.**
- **The performance of uphill and downhill walking with a WW is worse compared to walking level with a WW in novice WW users.**

Corresponding address

U. Lindemann
Department of Geriatrics and Clinic for Geriatric Rehabilitation, Robert-Bosch-Hospital
Auerbachstr. 110, 70376 Stuttgart, Germany
ulrich.lindemann@rbk.de

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Compliance with ethical guidelines

Conflict of interests. C. Becker has a financial relationship to Lilly company and Bosch company. U. Lindemann, M. Schwenk, Syn Schmitt, M. Weyrich and W. Schlicht declare that they have no competing interests.

Written informed consent was obtained from all individual participants included in the study prior to data collection.

All procedures performed in this study involving human participants were in accordance with the standards of the ethic committee of the local university and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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