

ORIGINAL ARTICLE

EPIDEMIOLOGY, CLINICAL PRACTICE AND HEALTH

Evaluating the sit-to-stand transfer assistance from a smart walker in older adults with motor impairments

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Aim: To evaluate the effectiveness and user satisfaction with the sit-to-stand (STS) assistance system of a smart walker (SW), and to identify factors associated with them in potential users.

Methods: A total of 33 older adults (29 women, aged ≥ 65 years) with motor impairments (habitual rollator use) and no severe cognitive impairment (Mini-Mental State Examination ≥ 17 points) carried out a Five-Chair Stand Test without assistance and five STS transfers with the STS assistance system. Based on the number of successfully completed STS transfers, success rates were calculated for the Five-Chair Stand Test and the SW-assisted STS transfers, and compared using the Wilcoxon signed-rank test. User satisfaction was assessed using the Tele-healthcare Satisfaction Questionnaire-Wearable Technology (0–80 points, higher score = higher satisfaction). Bivariate correlations and multiple linear regression analyses were used to identify participant characteristics associated with the success rate and user satisfaction with the STS assistance system.

Results: The success rate for the SW-assisted STS transfers was significantly higher than for the Five-Chair Stand Test ($93.3 \pm 12.9\%$ vs $54.5 \pm 50.6\%$, $P < 0.001$). User satisfaction was high (Tele-healthcare Satisfaction Questionnaire-Wearable Technology 62.5 ± 11.2 points). The success rate with the STS assistance system was not significantly associated with any participant characteristics. Higher body mass index was a significant independent predictor of higher user satisfaction.

Conclusions: The SW-integrated STS assistance system can provide effective STS support with high user satisfaction for a wide range of potential users. Our findings suggest the high potential of the STS assistance system for promoting mobility, independence and quality of life for older adults with motor impairments. *Geriatr Gerontol Int* 2020; 20: 312–316.

Keywords: elderly, evaluation studies, mobility limitation, robotics, walkers.

Introduction

The ability to transfer from a sitting to a standing position is a prerequisite for mobility, independence and quality of life (QoL) in older adults.^{1,2} However, personal determinants for the sit-to-stand (STS) transfer, such as muscle strength, motor planning and control, joint mobility, and balance,^{3,4} decline during the aging process,^{5,6} and many older adults show STS difficulties, which have been associated with increased risk of falling and subsequent disability, institutionalization and mortality among older adults.^{2,7} In nursing home residents, the STS transfer has even been identified as the activity most frequently carried out before falling.⁸ Assisting the STS transfer might therefore be highly beneficial for

older adults with STS difficulties to reduce their risk of falling, and to promote their mobility, independence and QoL.

Recent technological advances have led to the development of smart walkers (SW), which are no longer limited to only providing walking assistance, but integrate smart functionalities, such as obstacle avoidance, navigation assistance, fall prevention and/or gait tracking.⁹ Some SW can also provide STS assistance. Different technical solutions have been proposed for implementing such STS assistance into a SW, ranging from: (i) basic, passive solutions, in which the braking system of the SW is activated while the user grasps the handles and pulls themselves up from the sitting position; through to (ii) more active solutions, in which the SW motion is controlled in the forward direction to pull up the user from sitting while grasping the handles; to (iii) more complex,

active solutions, in which the user is assisted during the entire STS motion by specifically designed trajectories of a manipulated STS supporting element (e.g. forearm or chest support) to achieve optimal transfer characteristics.⁹ Independent of the technical implementation, previous evaluation studies of SW-integrated STS assistance systems suffer from methodological limitations, including small sample sizes, inadequate selection of participants, lack of assessment strategies specifically tailored to the STS assistance system, lack of user satisfaction measures and/or lack of inferential statistical analyses.^{10–13} To our knowledge, factors predictive for the effectiveness and user satisfaction have also not yet been investigated.

In a previous study, we described the technical details of the SW-integrated STS assistance system to be evaluated in the present study.¹¹ We also presented initial descriptive data on the effectiveness and user satisfaction with the system in potential SW users; however, we did not provide more detailed statistical analyses of these results and did not analyze participant characteristics that might have affected the effectiveness or user satisfaction.

In summary, the aim of the present study was to evaluate the effectiveness and user satisfaction with a SW-integrated STS assistance system, and to identify factors associated with them in potential SW users.

Methods

The present study was carried out between 1 November and 5 December 2014, with approval from the ethics committee of the Medical Faculty of the University of Heidelberg (S-358/2013) and in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants.

MOBOT smart walker

The four-wheeled SW used in this study was developed in the MOBOT project (“Intelligent Active MObility Aid RoBOT integrating Multimodal Sensory Processing, Proactive Autonomy and Adaptive Interaction”) and integrates innovative functionalities, such as STS assistance, obstacle avoidance, navigation assistance, user following, gait tracking and audio-gestural human–robot interaction into an overall context-aware mobility assistance robot.^{14–17} The STS assistance system is based on two actuated arms providing active assistance during the entire STS motion through individualized robot handle trajectories (positions, velocities, accelerations) specifically tailored to the user’s specific anthropometrics and motor impairment level. A detailed description of the STS assistance system and the optimal assistive strategies used to support the participants in the STS transfer has been provided previously.¹¹

Study population

Participants were recruited from rehabilitation wards of a geriatric hospital, from a hospital-associated geriatric rehabilitation sports

club and from nursing homes. Following the criteria for the defined SW users,¹⁷ the inclusion criteria were: age ≥ 65 years, moderate motor impairments (habitual rollator use in daily life and/or 4-m usual gait speed¹⁸ < 0.6 m/s) and no severe cognitive impairment (Mini-Mental State Examination¹⁹ score ≥ 17 points).

Measurements

Descriptive measures included age, sex, body mass index (BMI), Mini-Mental State Examination,¹⁹ Barthel Index,²⁰ Performance Oriented Mobility Assessment,²¹ 4-m usual gait speed test,¹⁸ falls in the previous year, Short Falls Efficacy Scale-International,²² 15-item Geriatric Depression Scale,²³ 12-item Short-Form Health Survey²⁴ and living situation (community dwelling *vs* institutionalized).

STS measurements started with the Five-Chair Stand Test (5CST) to assess the participants’ general ability to stand up from a sitting position without assistance.² As a standardized pre-test of the 5CST, participants were initially instructed to complete one chair stand (1CS). If they were unable to complete the 1CS after several trials, the 5CST was not carried out. Participants who successfully completed the 1CS, were instructed to carry out the actual 5CST (i.e. five STS transfers as fast as possible without assistance) once. The number of successful STS transfers in the 5CST and, if possible, the completion time for all five STS transfers in the 5CST were recorded. After the 5CST, participants tested the SW-integrated STS assistance system, which was initially adapted to the anthropometrics and motor impairment level of each participant to provide a user-specific optimal robot handle trajectory for the STS assistance. The SW was placed in front of the seated participants, and the SW handles were brought into the starting position such that they were in line with the participants’ trochanter major. Participants were then instructed to grip the handles and to trigger the STS assistance system by applying a small downward force on the handles, whenever they felt ready for the STS transfer. Each participant carried out five STS trials with assistance of the SW, including short pauses in between to avoid exhaustion and in which the handles of the SW were brought back to the initial starting position. Figure 1 shows a sequence of snapshots taken during an STS transfer with the STS assistance system. The number of successful STS transfers with assistance of the SW was recorded. For all STS measurements, participants were seated on an arm and backless, height-adjustable chair with the seat placed at 100% knee height, measured as the distance from the left medial tibia plateau to the floor.

User satisfaction with the STS assistance system was evaluated using the Tele-healthcare Satisfaction Questionnaire-Wearable Technology (TSQ-WT; Table S1).²⁵ The TSQ-WT consists of six dimensions evaluating the benefit, usability, self-concept, privacy and loss of control, QoL, and wearing comfort of a system. Each dimension includes five items rated on a 5-point Likert scale (0–4 points), with higher scores indicating more positive ratings. The

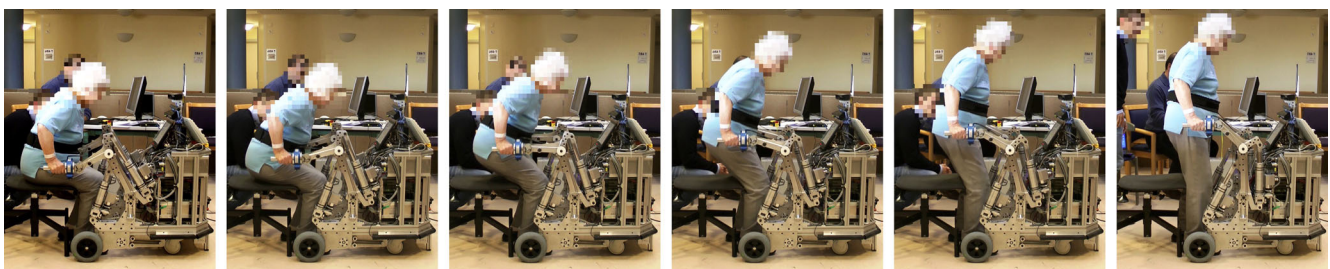


Figure 1 Sequence of snapshots taken during a sit-to-stand transfer with assistance of the smart walker.

TSQ-WT has already been successfully used to evaluate the navigation assistance system of the SW²⁶ and other robotic devices.^{27,28} It can be adapted to several systems, and was customized to the STS assistance system by deleting the inappropriate dimensions of wearing comfort, which focuses on wearable technology, and privacy and loss of control, which focuses on long-term technology use.

The main study outcomes were the: (i) success rates (%) for the 5CST without assistance (SR_{5CST}) and the STS trials assisted by the SW (SR_{SW}), both calculated as $(100 \times \text{number of successful STS transfers} / 5)$; (ii) TSQ-WT dimension scores (range 0–20 points), calculated as the sum of item scores; and (iii) TSQ-WT total score (range 0–80 points), calculated as the sum of the TSQ-WT dimension scores.

Statistical analysis

Descriptive data were presented as frequencies and percentages, means and standard deviations or medians and interquartile ranges. McNemar tests were used to compare the number of participants successfully completing the 1CS with those successfully completing the individual STS trials with the SW. The difference between the SR_{5CST} and the SR_{SW} was analyzed using the Wilcoxon signed-rank test. Effect size was calculated as (Z / \sqrt{N}) and interpreted as small (<0.3), moderate ($0.3 < 0.5$) and large (≥ 0.5).²⁹ To identify potential predictors of the effectiveness and user satisfaction with the STS assistance system, bivariate associations of participant characteristics with the SR_{SW} and TSQ-WT total score were examined using Spearman's rank or point-biserial correlations (r). The association of the TSQ-WT total score with the SR_{SW} was also analyzed by Spearman's rank correlation. Participant characteristics that showed significant correlations were entered into multiple linear regression models (stepwise backward) to determine independent predictors of SR_{SW} and TSQ-WT total score. A two-sided P -value of <0.05 showed statistical significance. Statistical analysis was carried out using IBM SPSS Statistics for Windows, version 25.0 (IBM Corporation, Armonk, NY, USA).

Results

The sample included 33 older persons (women $n = 29$, 87.9%) with a mean age of 84.6 ± 5.0 years and no severe cognitive impairment (MMSE score 24.9 ± 3.9 points) who all used a rollator as a mobility aid in everyday life (Table 1). Functional status was slightly impaired, with a median Barthel Index of 80.0 points (interquartile range 67.5–95.0 points). Habitual gait speed averaged 0.47 ± 0.13 m/s, and the mean Performance Oriented Mobility Assessment score was 20.0 ± 5.4 points, indicating low motor performance and increased risk of falling.

A total of 15 participants (45.5%) were not able to complete the unassisted 1CS. Already in the first trial with the STS assistance system, the number of participants who successfully completed the STS transfer was significantly higher than in the unassisted 1CS ($n = 28$, 84.8% vs $n = 15$, 45.5%, $P = 0.003$) and further increased over the subsequent trials (2nd: $n = 29$, 87.9% vs $n = 15$, 45.5%, $P = 0.003$; 3rd: $n = 31$, 93.9% vs $n = 15$, 45.5%, $P < 0.001$), with all participants achieving the standing position in the fourth and fifth trial ($n = 33$, 100.0%). All participants who carried out the unassisted 5CST ($n = 18$, 54.5%) completed five repeated STS transfers, with a mean completion time of 19.6 ± 7.6 s. The SR_{SW} was significantly higher than the SR_{5CST} ($93.3 \pm 12.9\%$ vs $54.5 \pm 50.6\%$, $P < 0.001$), with a large effect size (0.62). User satisfaction with the STS assistance system was high,

Table 1 Participant characteristics

Variables	$n = 33$
Age (years)	84.6 ± 5.0
Sex (female)	29 (87.9)
Body mass index (kg/m^2)	26.8 ± 3.3
Mini-Mental State Examination (score)	24.9 ± 3.9
Barthel Index	80.0 [67.5–95]
Performance Oriented Mobility Assessment, score	20.1 ± 5.4
Four-meter walk test (m/s)	0.47 ± 0.13
Fall in the previous year	21 (63.6)
Short Falls Efficacy Scale-International (score)	9 [7–12]
15-item Geriatric Depression Scale (score)	2 [1–3]
12-item Short Form Health Survey (score)	
Physical component	34.4 ± 9.6
Mental component	53.6 ± 9.4
Living situation	
Community-dwelling	26 (78.8)
Institutionalized	7 (21.2)

Data presented as mean \pm SD, n (%) and median [interquartile range].

with all median TSQ-WT scores in the upper quartile of the scoring range (Table 2).

None of the participant characteristics significantly correlated with the SR_{SW} ($r = |0.01-0.24|$, $P = 0.183-0.999$). BMI ($r = 0.45$, $P = 0.009$) and age ($r = -0.38$, $P = 0.031$) showed significant moderate correlations with the TSQ-WT total score, such that a higher BMI and younger age were associated with higher user satisfaction. All other correlations between the TSQ-WT total score and participant characteristics were not significant ($r = |0.01-0.29|$, $P = 0.156-0.905$). No significant correlation was also found between the TSQ-WT total score and the SR_{SW} ($r = -0.26$, $P = 0.148$). In the linear regression model, only a higher BMI was identified as a significant independent predictor of higher user satisfaction ($\beta = 0.48$, $R^2 = 0.23$, $P = 0.005$).

Discussion

The present study shows that the SW-integrated STS assistance system was highly effective for supporting the STS transfer in older adults with motor impairments. To our knowledge, this is the first study that provides statistical evidence on the effectiveness of such a system in the intended user group of a SW. Our results further show high user satisfaction with the STS assistance system

Table 2 User satisfaction with the sit-to-stand transfer assistance system of the smart walker: Dimension scores and total score of the Tele-healthcare Satisfaction Questionnaire-Wearable Technology

TSQ-WT dimension	n	Mean \pm SD	Median (IQR)
Benefit (0–20 points)	33	15.5 ± 4.4	16 (13–19)
Usability (0–20 points)	33	16.7 ± 2.9	17 (15–19)
Self-concept (0–20 points)	33	14.6 ± 3.7	15 (13–20)
Quality of life (0–20 points)	33	15.1 ± 3.2	16 (13–20)
Total score (0–80 points)	33	62.5 ± 11.2	62 (56–71)

Data presented as mean \pm SD and median (interquartile range [IQR]). TSQ-WT, Tele-healthcare Satisfaction Questionnaire-Wearable Technology (higher scores indicate more positive ratings).

among potential SW users, with those having higher BMI being more satisfied.

The general STS ability of the participants was low, with only approximately half of them able to stand up unassisted. Already in the first trial with the STS assistance system, a significantly higher proportion of participants achieved the standing position, suggesting that the system can initially provide an easy-to-handle and effective STS assistance for potential users. Participants initially not able to stand up with the STS assistance system also became quickly familiar, as shown by the finding that all participants achieved the standing position with its assistance not later than with the fourth trial. As documented by the significantly higher success rate with the STS assistance system than without its assistance, the added value of this system for the intended user group is evidenced by statistical analysis, which was lacking in previous evaluation studies of SW-integrated STS assistance systems.^{10–12}

Based on a comprehensive questionnaire, the present results showed high user satisfaction with the STS assistance system in several dimensions. To our knowledge, such a multidimensional subjective evaluation measure has not yet been used in previous studies for evaluating such SW-integrated systems. High scores across the different dimensions emphasized that: (i) the STS assistance system provided a benefit for the participants by helping them to stand up; (ii) it was perceived as easy-to-use, not requiring much effort and not causing feelings of insecurity or indisposition; (iii) its use was an interesting challenge for them, and they were not reminded of losing their independence nor would they feel embarrassed when using it in public; and (iv) it could have the potential for promoting the user's well-being, social contacts, independence and QoL.

The user satisfaction with the STS assistance system was high compared with that previously reported for the SW-integrated navigation assistance system, as also assessed using the TSQ-WT in a similar study population.²⁶ Regarding the satisfaction in different dimensions, it even seems that potential users might perceive a SW-integrated STS assistance system as being more beneficial and having a greater potential to improve their QoL than a SW-integrated navigation assistance system.

The success rate with the STS assistance system was not related to specific participant characteristics, suggesting that it might be effective for a wide range of potential SW users. The individualized assistive STS strategy in terms of adapting the robot handle trajectory of the STS assistance system to the specific participant might explain this finding.

Higher user satisfaction was found to be independently associated with higher BMI. A potential explanation for this might be that participants with higher BMI had to exert more physical effort to successfully complete the unassisted STS transfer and therefore perceived the reduction of physical exertion from the STS assistance system more clearly than participants with lower BMI, who usually perceived less physical exertion when completing functional tasks.³⁰ Measuring the perceived physical exertion in future studies evaluating SW-integrated STS assistance systems might provide further support for this explanation.

User satisfaction was not related to the success rate with the STS assistance system, indicating that participants who initially had difficulties in standing up with the SW were still satisfied with the STS assistance system. The failed trials in the initial phase of using the system seem to have been well-accepted by the participants and did not negatively affect their user satisfaction.

The strength of the present study was its approach to avoid the methodological limitations of previous studies evaluating STS assistance systems or other innovative SW functionalities.¹³ It

extends the previous research by including a reasonable number of representative SW users; using a comparative study design for effectiveness testing (i.e. unassisted *vs* assisted STS transfer) and an assessment strategy specifically tailored to the STS assistance system to document its specific effect; using a comprehensive questionnaire on the user satisfaction with the STS assistance system; investigating potential factors associated with the effectiveness and user satisfaction; and analyzing data obtained by statistical methods.

The study also had some limitations. Although our sample size was much larger than in previous studies evaluating SW and integrated STS assistance systems, it was relatively small, which might have limited the statistical power. However, post-hoc power analyses showed a power of 92.3–92.9% for the McNemar tests (OR 11.1–12.1, $\alpha = 0.05$, $\pi_D = 0.363$ – 0.364), 98.6% for the Wilcoxon signed-rank test ($d_z = 0.77$, $\alpha = 0.05$) and 86.0% for the linear regression model ($R^2 = 0.23$, $\alpha = 0.05$, number of predictors = 1). Our participants were predominantly women, limiting the generalizability of the results to men. Consequently, the finding that sex was not related to the effectiveness and user satisfaction with the STS assistance system might have also been limited by the small number of male participants. The five STS trials with the STS assistance system included short pauses in between, whereas the 5CST had to be carried out as fast as possible without pauses. This could have led to a reduced SR_{5CST} due to exhaustion; however, all participants able to carry out the 5CST achieved the maximum SR_{5CST} of 100% despite maximum STS pace. The STS assistance system was tested only for a small number of trials within a controlled laboratory environment, as limited by the prototype status of the SW. Future studies with a more advanced version should include evaluations after prolonged use in more natural environments.

In conclusion, the present study highlights that the SW-integrated STS assistance system can provide effective support for the STS transfer of potential SW users, with high user satisfaction. Our findings suggest the high potential of the STS assistance system to promote mobility, independence and QoL in older adults with motor impairments. Future SW developments might consider the implementation of STS assistance systems that allow for individual adaptation to the user.

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Disclosure statement

The authors declare no conflict of interest.

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Supporting information

Additional supporting information may be found in the online version of this article at the publisher’s website:

Table S1 Tele-healthcare Satisfaction Questionnaire-Wearable Technology adapted to the evaluation of the sit-to-stand assistance system of the smart walker.

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