Evaluation Studies of Robotic Rollators by the User Perspective: A Systematic Review

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Abstract— **Robotic rollators enhance basic functions of established devices by technically advanced physical, cognitive, or sensorial support to increase autonomy in persons with severe impairment. In the evaluation of such Ambient Assisted Living (AAL) solutions, the user perspective is essential to ensure the safety, prove the usability and demonstrate the effectiveness for the target user group. This work presents a systematic review of studies that evaluated robotic rollators with focus on the user perspective. The literature search was conducted in PubMed and IEEE Xplore. Twenty-eight studies were identified that met predefined inclusion criteria. There was a large heterogeneity in definitions of potential users, study population, study design, and assessment methods. We found major methodological shortcomings related to sample descriptions, sample sizes, assessment instruments, and statistical analyses of study results. Recommendations for future evaluation studies include: clear definition of target user group, adequate study subjects, and adequate user-focused assessment strategy with established, standardized and validated methods to allow comparability of study results. Assessment strategies may focus on specific robotic functionalities allowing an individually tailored assessment of innovative features to document their added value.**

I. Introduction

The ability to move independently represents a hallmark of autonomous living [1] and quality of life [2]. However, motor, sensory or cognitive impairment restrict mobility in frail, older persons [3]. To overcome or compensate such impairments, in the field of Ambient Assisted Living (AAL), robotically augmented rollators with various robotic features and functionalities have been developed providing physical support, sensorial assistance, cognitive assistance, and/or health monitoring [4]. The development and evaluation of such high-tech devices is still a new, emerging research field which have been so far mainly driven by technical engineering goals. However, in addition to the technical perspective, which focused predominantly on the functional capability of devices, the user perspective including users' performance, experience, and physical demands with the robotic devices, is essential to ensure the safety, prove the usability and demonstrate the added value for the target user group, and should guide the development and evaluation of assistive devices [5]. However, the change from technical to user perspective may lead to specific methodological challenges including the study design and assessment strategies. To our knowledge, no systematic review on the evaluation of robotic rollators with focus on the user perspective has been published. Therefore, the objective of this systematic review was to summarize methods and results of studies which evaluated the interaction between users and robotic rollators, and to give recommendations for future evaluation studies.

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II. Methods

The literature search was conducted using the electronic databases PubMed and IEEE Explore. Initial search terms were compiled and iteratively refined by team members with expertise in the clinical and in the technical area. Search terms were adapted to the databases and comprised both controlled vocabulary (i.e. MeSH Terms, IEEE Terms) and keywords of relevance identified during searches. Manual searching was performed to identify additional studies by hand-searching reference lists of relevant articles and reviews and by reviewing key authors' own databases.

Titles and abstracts of retrieved references were screened if they met pre-specified inclusion criteria. Studies were searched with focus on evaluation or clinical results of an experiment, trail, or intervention in human beings with a robotic rollator (or wheeled walker) independent of type of outcome measurements. Single case reports were excluded. For the purpose of this review the term "robotic" includes the normal function of a rollator enhanced by additional physical, cognitive or sensorial robotic support while walking, also including STS transfers. The search was limited to articles in English language, and databases were searched until December 31st, 2014.

The study selection process was conducted following the methodology as suggested by the method guidelines of the Cochrane Collaboration [6]. After inclusion, data on definition of user group, study sample, study design, assessment methods, and study results were extracted for each study..

III. Results

A total of 8,989 articles were identified through database searching, and another 79 were added by manual searching. After removing duplicates and screening title and abstracts, 235 were found to be related to the search topic. After reviewing full text and applying our inclusion criteria, we identified 28 studies published between 2001 and 2014 to be included in the review.

A. User Group Definitions

For almost all robotic rollators, a target user group was mentioned; however, definition of potential users differed considerably in accuracy and explicitness. Most articles provided a generic description in broad terms (e.g. elderly people), defined users based on setting characteristics (e.g. persons in nursing and assisted living homes), or gave non-

specific impairment-/disease-related definitions (e.g. patients with mobility problems, post-stroke patients). Specific impairment-related definitions based on established, validated assessment methods (e.g. Functional Ambulation Classification, Walking Index for Spinal Cord Injury) were documented in only few articles.

B. Study Samples

The mean sample size of studies providing precise information on number of subjects was 7.2 ± 4.3. Study samples differed substantially with respect to age, impairments, or diseases. Subjects' age ranged from 14 to 97 years. Half of the studies included subjects with motor, functional, cognitive, visual and/or neurological impairments. In the other half, a convenience (e.g. ordinary adult males), mixed (e.g. healthy subjects and subjects with motor/cognitive impairment) or setting-specific sample (e.g. residents of retirement facility) was used. In only few studies, subjects' motor-functional or cognitive impairment level was defined based on established and validated screening instruments or assessment methods (e.g. Mini-Mental State Examination, 4-meter walk test, Timed Up and Go). In a number of studies, subjects did not match with the predefined user group of the developed device.

C. Design of Studies

Depending on study objectives, three different types of studies/experiments were performed:

(1) *Observational studies/experiments* which focused predominantly on the verification of technical capability and/or on the subjective user evaluation of robotic devices and which presented relevant information or data solely descriptively without providing any reference values.

(2) *Comparative studies/experiments* in which (a) robotic devices and conventional devices (e.g. folding walker, wheeled walker) or unassisted walking/STS transfers were compared; (b) different assistance levels (e.g. activated vs. non-activated obstacle avoidance), interface designs, or development stages of functionalities within the same robotic device were compared; (c) the user experience with the robotic device or the motion behavior of the robotic device was compared before and after/over a series of trials, and (d) in which outcomes of a newly developed robotic functionality and those of an external reference measurement was compared.

(3) *Interventional studies* in which some type of training opportunities with the robotic devices were offered to the subjects.

D. Statistical Analysis

A statistical analysis of outcomes was included in only few studies identified in this review. In the vast majority of studies, results were presented using solely descriptive data.

E. Assessment Methods

Assessment measures used in identified studies were distinguished into five categories:

(1) Established *clinical performance-based measures* (e.g. 4MWT, TUG) to assess subjects' functional ability to complete a requested task with or after the use of the robotic device mainly by simple quantitative outcomes (e.g. gait speed, walking distance, rating score).

(2) Self-designed performance-based measures (e.g. navigational tasks, walking/obstacle courses) specifically tailored to specific functionalities of the robotic device (e.g. guidance system, obstacle avoidance). Such *tailored assessment methods* predominantly used more technique-based and qualitative outcomes (e.g. path deviation, distance to obstacle).

(3) Assessment methods to evaluate subjects' *physical and physiological demands* during the use of the robotic devices (e.g. respirometry, electromyography, force measurements).

(4) *Technical evaluation measures* to assess the technical capability of the robotic device and its integrated functionalities. (we renounce more detailed information on these measures since they have very limited relevance for the user perspective)

(5) *Subjective evaluation measures* to assess the user experience with the robotic device (e.g. user comments, non-standardized surveys, structured questionnaires).

F. Study Results

In *clinical performance-based measures*, subjects showed most frequently inferior user performance (i.e. gait speed, task completion time) with the motorized high-tech rollators when compared to conventional walkers. However, robot-assisted ambulation training was reported to result in improved gait and functional performance, compared to conventional ambulation training on parallel bars.

In *tailored assessment methods* covering technically advanced outcomes specifically adjusted to the specific functionality (walking distance, path deviation, distance to obstacles), study results suggest that activated high-tech functionalities (i.e. obstacle avoidance, guidance/navigational assistance) allow superior performance when compared to conventional devices or to the same robotic device with non-activated functionalities. In less specific outcomes such as walking time or walking speed, subjects seemed, however, to achieve superior performance with the non-motorized, low-tech devices.

Studies assessing subjects' *physical and physiological demands* with robotic devices showed heterogeneous results. Overall, the use of motorized high-tech devices seem to be not less physically or physiologically demanding than the use of low-tech devices.

Independent of the different assessment methods (i.e. user comments, structured questionnaires), results of *subjective evaluation measures* showed that robotic devices or specific robotic functionalities were generally positively perceived by the subjects. Only few device properties were negatively commented (e.g. bulkiness, portability, adaptability, full robot motion control mode) by the subjects.

IV. Discussion

The purpose of this systematic review was to summarize assessment strategies and results of evaluation studies on robotic rollators with focus on the user perspective. Identified studies showed large heterogeneity in definitions of potential users, study population, study design, and assessment methods. We found major methodological shortcomings related to insufficient sample descriptions and sample sizes, lack of appropriate, standardized and validated assessment instruments, and lack of statistical analysis of study results. No generic assessment strategy could be identified, while objectives of studies and study designs differed substantially. Consequently, it was not appropriate to conduct a meta-analysis.

V. Conclusions

Apart from the heterogeneity of studies methodological deficits in most of the identified evaluation studies became apparent. Recommendations for future evaluation studies include: (1) clear definition of target user group by valid, impairment-based criteria; (2) adequate selection of study subjects representative of potential users; (3) selection of established, standardized, and validated assessment methods to allow comparison of study results; (4) specifically tailored assessment strategy focusing on specific robotic functionalities to document the added value of the innovative features; and (5) statistical analyses of study results. These recommendations given for robotic rollators may also apply in general for the development and evaluation of AAL systems with a focus on the user perspective.

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References

[1] M. Hirvensalo and T. Lintunen, "Life-course perspective for physical activity and sports participation," *European Review of Aging and Physical Activity*, vol. 8, pp. 13-22, 2011/04/01 2011.

[2] E. J. Groessl, R. M. Kaplan, W. J. Rejeski, J. A. Katula, A. C. King, G. Frierson, *et al.*, "Health-related quality of life in older adults at risk for disability," *Am J Prev Med*, vol. 33, pp. 214-8, Sep 2007.

[3] S. I. Chaudhry, G. McAvay, Y. Ning, H. G. Allore, A. B. Newman, and T. M. Gill, "Geriatric impairments and disability: the cardiovascular health study," *J Am Geriatr Soc*, vol. 58, pp. 1686-92, Sep 2010.

[4] A. Frizera-Neto, R. Ceres, E. Rocon, and J. Pons, "Empowering and assisting natural human mobility: the simbiosis walker," *Int J Adv Robot Syst*, vol. 8, pp. 34-50, 2011.

[5] European Commission, "*Guidelines on medical devices. Clinical evaluation: A guide for manufacturers and notified bodies*," 2009. http://ec.europa.eu/health/medical-devices/files/meddev/2_7_1rev_3_en.pdf.

[6] J. Higgins and G. S, *Cochrane handbook for systematic reviews of interventions*. Chichester, UK: John Wiley & Sons, 2011.